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Semi-Annual Status Report

RESEARCH IN MILLIMETER WAVE TECHNIQUES

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Project Monitor for NASA/GSFC
J. L. King

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Electromagnetics Laboratory

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FOREWORD

This is the seventh semi-annual status report on NASA Grant NSG-5012. The Grant period is from June 15, 1974 to January 31, 1978 and includes five extensions and increases to the scope and funding of the programs. The total funding to date is $423,933 of NASA funds and $22,681 in Georgia Tech cost-sharing funds, for a total from both sources of $446,614. Current grant funding is at a level of $150,000 with Georgia Tech providing $7,500, and the current grant period extends through January 31, 1978. A proposal for extension of the grant period through the 12-month period ending January 31, 1979 has been submitted to NASA/GSFC. This proposal calls for a funding level of $115,606 with Georgia Tech providing $5,606 in cost-sharing funds.

As indicated in previous reports, and although not required by the Grant, informal monthly letter-type reports have been written and furnished to the NASA/GSFC technical monitor, J. Larry King, in order to keep him abreast of project activities on a current basis. We believe this provides a better opportunity for NASA to direct the technical efforts on the program for the maximum benefit of the government. Copies of each of these monthly reports for the current period (thirty-seven through forty-one) are attached as an Appendix. This seventh semi-annual report will replace the forty-second monthly letter (since this semi-annual report is being furnished during the time the forty-second monthly report would normally be written).

Responsibility for technical effort on this grant lies in the Electromagnetics Laboratory, under the general supervision of J. W. Dees, Director. R. W. McMillan has been appointed Principal Investigator of this program, which has the internal project number A-1642. The program technical effort is divided between the Radiation Systems Division, responsible for source and mixer development, and the Electro-Optics Division, responsible for radiometric measurements, quasi-optical techniques, and analysis. Contributors to the technical effort and/or this report during the seven six-month periods include: V. T. Brady, J. W. Dees, J. J. Gallagher, D. O. Gallentine, J. B. Langley, R. W. McMillan, H. Muzika, J. H. Rainwater, J. M. Schuchardt, R. G. Shackelford, G. T. Wrixon (consultant), and Student Assistants C. H. Branch, A. M. Cook, R. E. Forsythe, H. Homayun,

N. K. O'Rourke, W. M. Penn, and D. H. Smith.

The following papers, based on work supported wholly or partially by this grant, have been presented or accepted for presentation or publication as noted, during the period covered by this report.

1. J. H. Rainwater, J. A. Stratigos, J. M. Schuchardt, R. W. McMillan and J. L. King, "Radiometric Measurements Near 183 GHz", Sixth ARPA/Tri-Service Millimeter Wave Conference, Harry Diamond Laboratories, Adelphi, Md., November, 1977.

The following papers have been accepted for presentation at the Third International Conference on Submillimeter Waves and Their Applications to be held at the University of Surrey in Guildford, England in late March, 1978.

2. J. J. Gallagher and R. W. McMillan, "Prediction of the Existence of a Sharp Peak In Water Vapor Emission Lines In Down-Looking Radiometry".
3. J. H. Rainwater and R. W. McMillan, "Measurement of the Radiometric Antenna Temperature Spectrum Due to the 183.3 GHz Water Vapor Transition".
4. G. T. Wrixon and R. W. McMillan, "Measurements of Earth-Space Attenuation at $\lambda = 1.3$ mm".
5. R. W. McMillan, C. H. Branch, and G. M. Lamb, "Polarization-Twisting, Bandpass-Tunable Fabry-Perot Filters for Submillimeter Applications".

In addition, the fourth paper listed above has been accepted for publication in IEEE Transactions on Microwave Theory and Techniques, and should be published in mid-1978.

During the period covered by this semi-annual report, a trip was made by J. W. Dees, J. J. Gallagher, R. W. McMillan, J. H. Rainwater, J. M. Schuchardt, and J. A. Stratigos to Harry Diamond Laboratories, Adelphi, Maryland to attend the Sixth ARPA/Tri-Service Millimeter Wave Conference on 29 and 30 November 1977. This trip was related to the areas of technology covered by the grant, but not necessarily charged to it.

1.0 INTRODUCTION

During the past six months, efforts on this project have been devoted to: (1) continuation of construction and testing of a 6 GHz subharmonic mixer model with extension of the pumping frequency of this mixer to $\omega_s/4$, (2) construction of a 183 GHz subharmonic mixer based on the results of tests on this 6 GHz model, (3) ground-based radiometric measurements at 183 GHz, (4) fabrication and testing of wire grid interferometers, (5) calculations of reflected and lost power in these interferometers, and (6) calculations of the antenna temperature due to water vapor to be expected in down-looking radiometry as a function of frequency. Significant events during the past six months include: (1) Receipt of a 183 GHz single-ended fundamental mixer designed to serve as a back-up to the subharmonic mixer for airborne applications, (2) attainment of 6 dB single sideband conversion loss with the 6 GHz subharmonic mixer model by using a 1.5 GHz ($\omega_s/4$) pump frequency, (3) additional ground-based radiometric measurements showing good agreement with theory near the absorption line peak, and (4) derivation of equations for reflection and loss for wire grid interferometers. Each of these areas of effort and achievement are treated in this report.

2.0 MIXER DEVELOPMENT

2.1 Fundamental Mixers

Dr. G. T. Wrixon of University College, Cork, Ireland, who served as a consultant to this program for one and one half years, designed a 183 GHz fundamental mixer to serve as a back-up device to the subharmonic mixer for airborne applications. This mixer was discussed in the semi-annual progress report of 15 July 1977, and features a split block construction to ease diode chip contacting and an integral IF matching filter for IF's up to 14 GHz.

This mixer was ordered from Custom Microwave of Longmont, Colorado and has recently been received. Figure 1 is a photograph of this device.

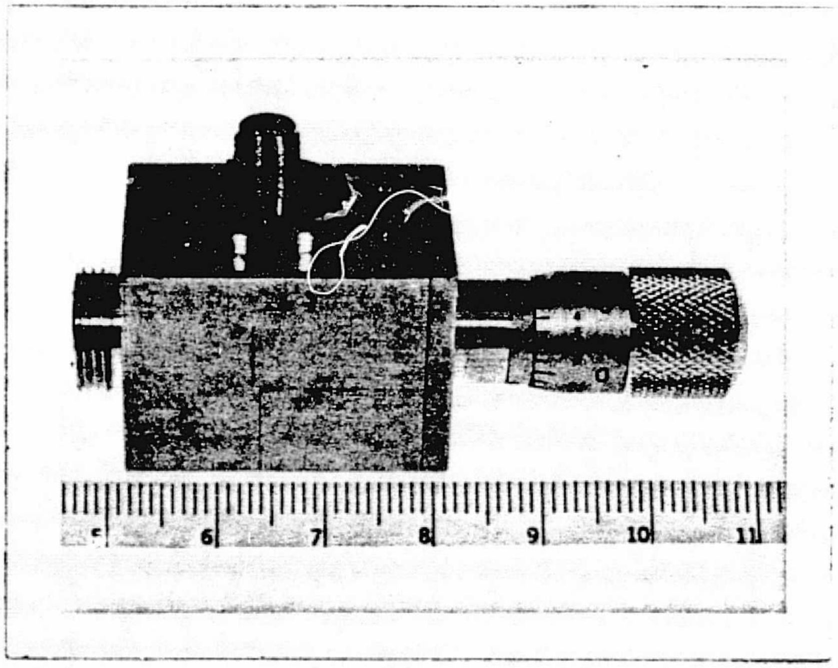

Figure 1. Split block mixer for 183 GHz.
The scale is in centimeters.

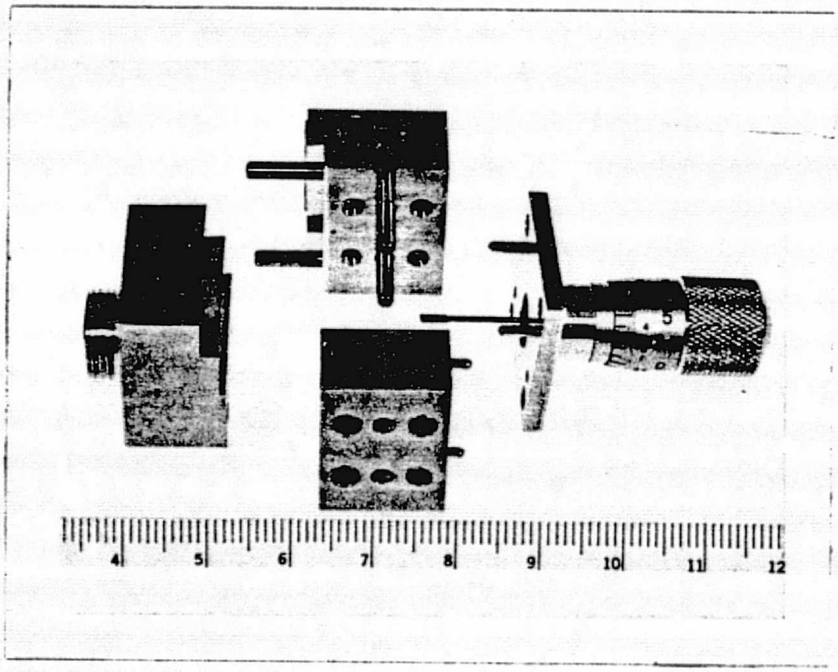

Figure 2. Split block mixer shown disassembled.

Figure 2 shows the same mixer disassembled showing the split block construction. Because of the ease of mounting and removing the Schottky barrier diode chips used in these devices, this mixer will be used to test and compare diode chips received from Drs. Bob Mattauch and Gerry Wrixon. This testing effort has been delayed for several months because of generally late deliveries from Custom Microwave, but will begin shortly when work on the subharmonic mixer permits.

The cross-guide mixer used in the ground-based radiometer has been repaired and some additional measurements of atmospheric emission near 183 GHz are being made. The results of these measurements will be given in subsequent monthly progress reports. An IF matching filter has been made for this mixer but has not yet been installed because of the time required for installation and testing. This filter is designed to match the mixer diode output to the IF amplifier over a wide range of signal frequencies to reduce fluctuations in performance caused by tuning the radiometer. It was decided that the time required for installation of this device should be spent in work on the subharmonic mixer.

It is proposed to replace this cross-guide mixer with a ridged waveguide, quasi-optic mixer as shown in Figure 3. The ridged waveguide provides simultaneous single-mode propagation for two different frequencies, so that both signal frequency f_s and local oscillator frequency $f_s/2$ will be propagated. The Fabry-Perot filter placed at the input to the mixer transmits the signal frequency, reflects the 90 GHz local oscillator frequency, and rejects the third harmonic of the local oscillator so that the 270 GHz "cold sky" will not be seen. This mixer is being developed under another program at EES and will be available to the proposed Grant for the cost of fabrication only. A significant improvement in the quality of the data obtained with the 183 GHz radiometer is expected with the use of this device.

2.2 Subharmonic Mixers

In building a subharmonic mixer of the type that is being built for this grant it is necessary to bond both a diode chip and a contacting spring to the stripline filter circuit. The diode is first bonded with

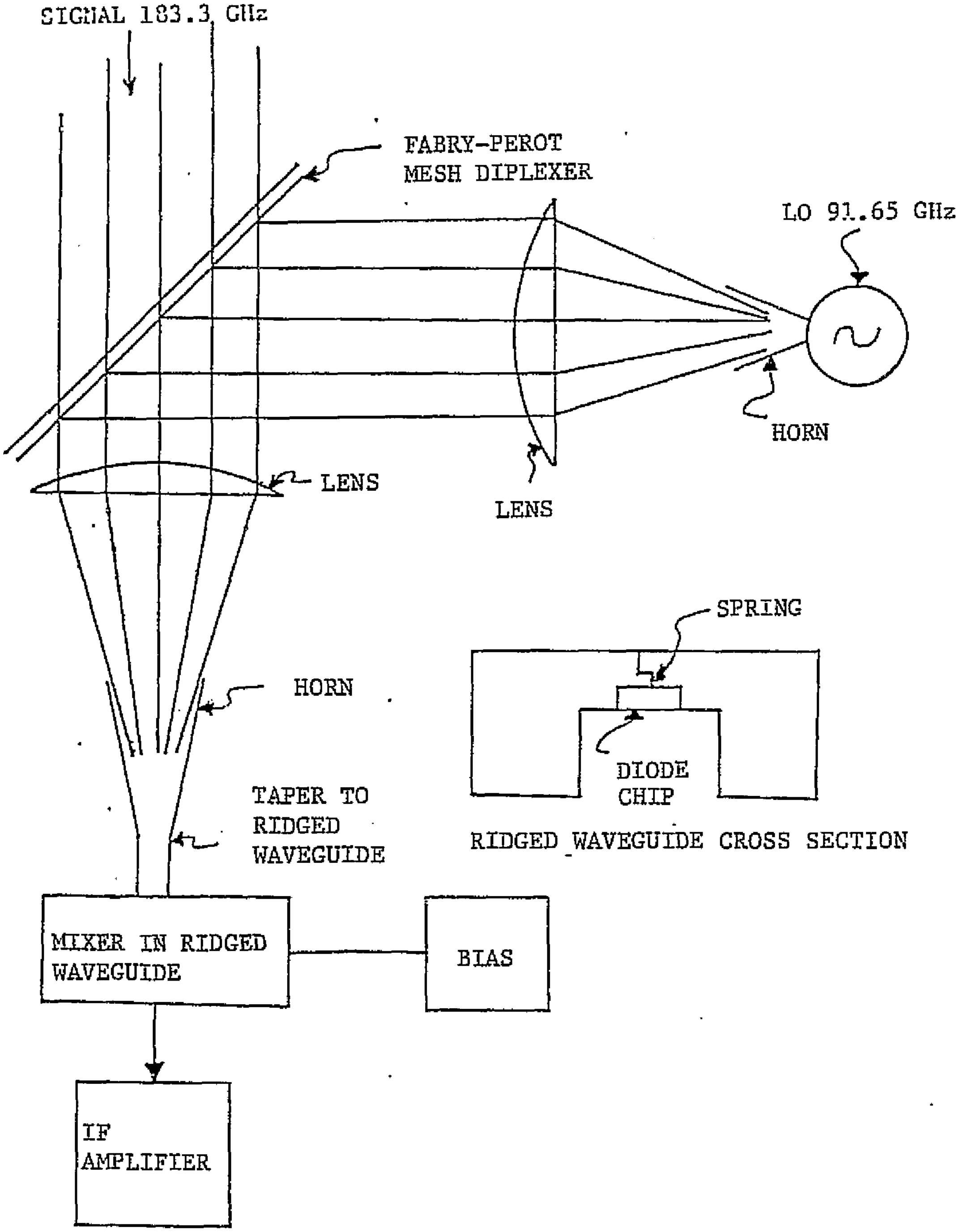

Figure 3. Schematic diagram of ridged waveguide quasi-optical mixer.

solder, followed by the spring wire which is affixed with lower temperature solder. Recently, some problems have been experienced with the spring wire breaking away from the stripline while being formed into a spring. It was considered necessary to form the spring after bonding so that the correct relationship between spring orientation and diode placement could be maintained. This problem has been solved by preforming the spring and using a 3-axis translator to maintain proper spring orientation while soldering the spring to the stripline. In this way a spring bond is made which will hold the weight of the stripline circuit without breaking. It is expected that the next difficult problem to be encountered in mixer fabrication will be in simultaneous contacting of the two mixer diodes. Pictures of this mixer are shown in the thirty-eighth monthly progress report (MPR) included in the appendix to this report.

During the last two months, some progress has been made in building a mixer model designed to operate with a local oscillator input frequency of $f_s/4$, where f_s is signal frequency. It will be recalled that the original subharmonic mixer model was designed for easy conversion to this configuration. Figure 4 shows the result of measuring the single sideband conversion loss of this mixer at 6.7 GHz with a local oscillator input of 1.7 GHz. The mixer was tuned to minimize conversion loss under the conditions given on the figure. This result shows that conversion loss remains constant at 6 dB over almost 60 dB change in RF input power. Figure 5 shows conversion loss as a function of RF input frequency with the mixer optimized at 6.7 GHz. Figure 6 gives both conversion loss and total system noise figure as a function of the local oscillator power input level. In this case the mixer was tuned to give minimum system noise figure instead of minimum conversion loss. It was also noted that both upper and lower sidebands have identical performance under this condition.

Performance curves for $f_s/2$ pumping are given in the semi-annual status report dated 15 July 1977. Comparison of these curves with Figures 4, 5, and 6 shows that the performance of the $f_s/4$ mixer model is comparable to that of the $f_s/2$ model. Based on these results, the $f_s/4$ configuration should be examined more closely because of the advantages of lower frequency pumping for both solid state and tube type local oscillators.

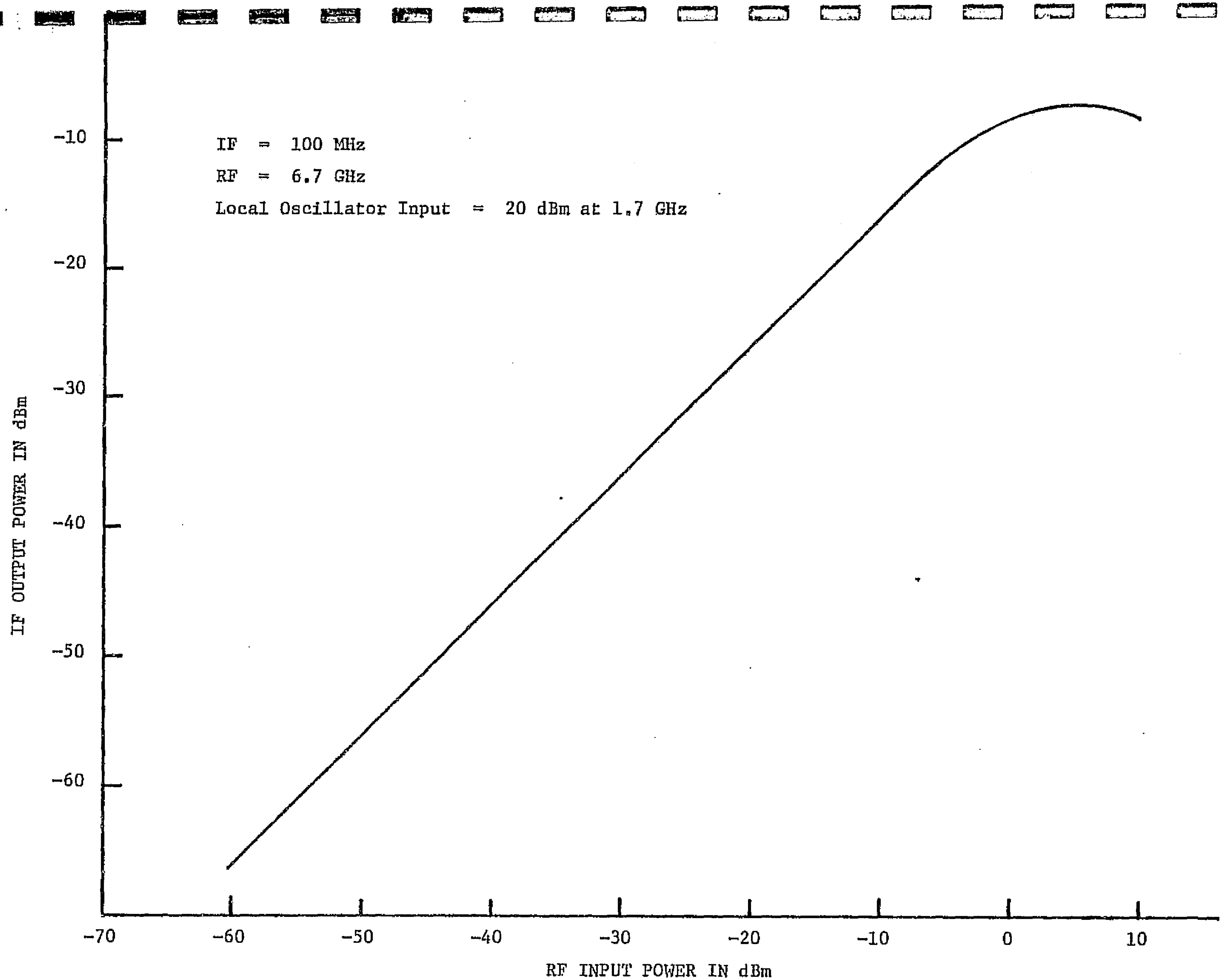

Figure 4. Single sideband conversion Loss for $f_s/4$ subharmonic mixer.

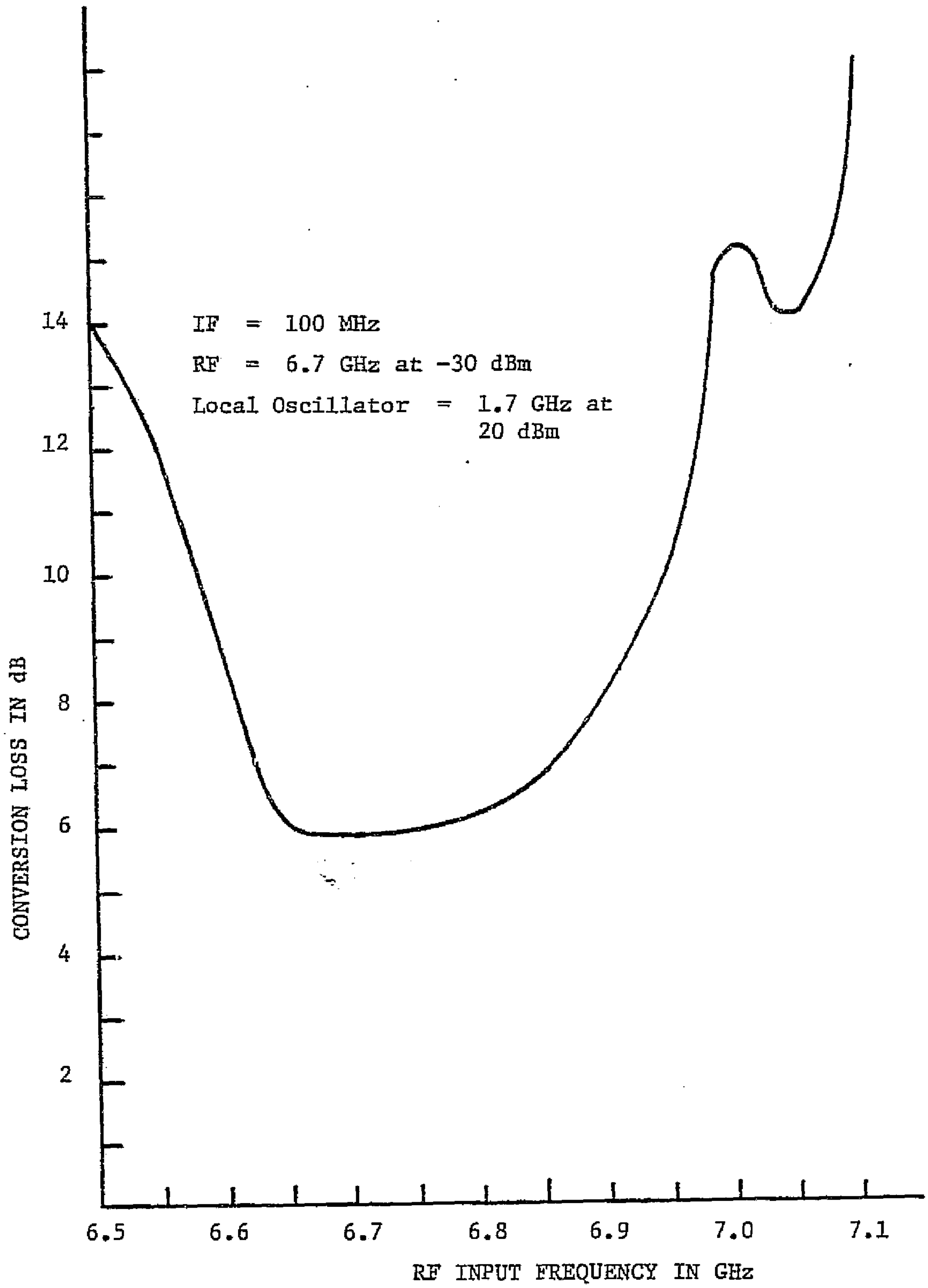

Figure 5. Conversion loss as a function of RF input frequency.

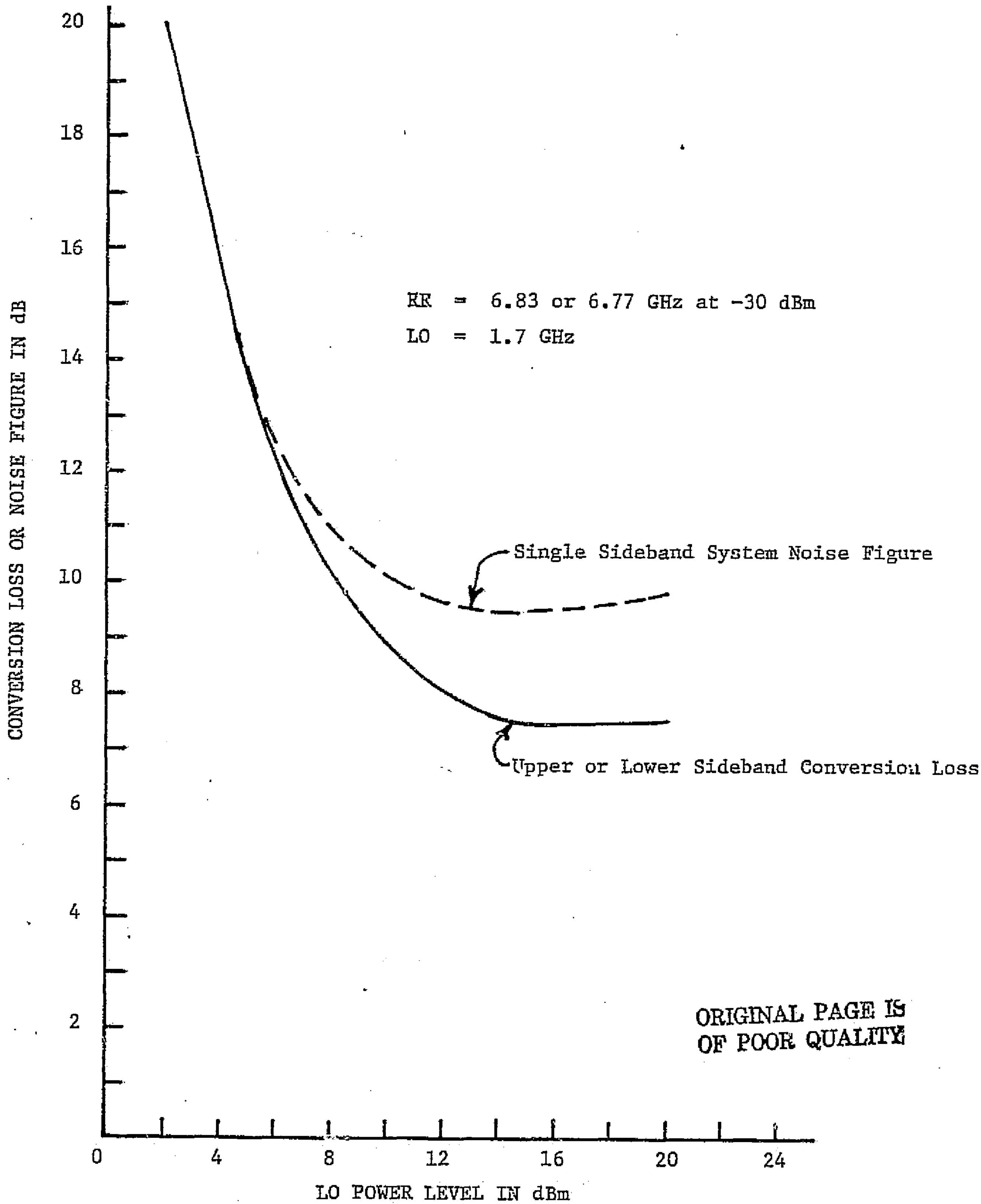

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Figure 6. Conversion loss and total system noise figure as a function of local oscillator input level.

3.0 RADIOMETRIC CALCULATIONS

During the six month reporting period ending 15 June 1977, some calculations were made which predicted the shape of water vapor emission lines when viewed from orbit or from extremely high altitudes. These calculations were performed to analyze results obtained by the Georgia Tech radiometer on board the NASA Convair 990 aircraft during data gathering flights in the early spring of 1977. The antenna temperatures predicted were compared to those measured by the airborne radiometer near 183 GHz. These calculations are discussed in the semi-annual progress report dated 15 July 1977.

The height distribution of atmospheric water vapor has been the subject of dispute for many years. Currently, there is a substantial body of data which suggests that H_2O concentration decreases rapidly with altitude to a density of about 10^{-3} g/m^3 at about 20 km and then starts to increase again with increasing height. In this section analytical evidence is presented for the existence of a sharp peak superimposed on emissions from the stronger H_2O lines which should be observable in down-looking radiometry. The variation in shape of this peak as a function of the stratospheric water vapor distribution is analyzed.

The background temperature T_B measured by a radiometer looking downward from altitude h at an angle θ to the vertical is given by

$$T_B = \int_h^0 T(Z)\exp[-\tau(h,Z,\theta)]\alpha(Z)\sec\theta dZ \tag{1}$$

$$+ R\exp[-\tau(0,h,\theta)]\int_h^0 T(Z)\exp[-\tau(Z,0,\theta)]\alpha(Z)\sec\theta dZ + (1-R)T_E\exp[-\tau(0,h,\theta)] ,$$

where T_E is the earth temperature and $T(Z)$ is the temperature of a stratum of atmosphere of thickness dZ located at altitude Z. The terms of the form $\tau(Z_1,Z_2,\theta)$ are the optical depths between altitudes Z_1 and Z_2 at angle θ, and R is the reflectivity of the earth. The term $\alpha(Z)$ is the atmospheric attenuation coefficient, and is dependent on a number of variables including temperature, pressure, water vapor density, and the form of the emission line shape parameter. The effect of an absorption continuum was not considered in these calculations because there is no analytical basis for its inclusion. In Equation (1), the first term is

the direct emission of the atmosphere, the second term is atmospheric emission reflected from the earth, and the third term is the emission of the earth modified by the atmospheric attenuation between the ground and altitude h.

Equation (1) was numerically integrated over the frequency range 100-700 GHz to a height of 50 km using the nine strongest water vapor absorptions below 1000 GHz, and the results of this integration are shown graphically in Figure 7. In making this calculation, a water vapor distribution with a secondary maximum at an altitude of 27 km was assumed. Note the presence of the characteristic peaks caused by this high altitude water vapor.

The rather strange shape of the predicted emission from high altitude H_2O is caused by a combination of several factors. In regions of low attenuation between lines, the radiometer is able to "see" far into the atmosphere to warmer air layers and to the earth itself. At frequencies falling on the skirts of the lines, absorption is greater and the radiometer sees only the colder upper atmospheric layers. Finally, at the line center frequencies, the absorption is very large and the radiometer sees only a short distance into the atmosphere. However, at these great altitudes, the atmosphere is warm, thus the region near the line center frequency shows a sharp peak in emission due to these warm layers. Because of the relatively high temperature and the low pressure in the stratosphere, it is difficult to conceive of a high-altitude water vapor distribution which does not exhibit these sharp peaks on emission line centers.

Several different upper atmospheric water vapor distributions have been analyzed, and each gives a different emission line shape. Figure 8 shows the water vapor profiles that have been used, and the numbers designating these distributions.correspond to those on the antenna temperature curves for the 183 GHz water vapor line shown in Figure 9. Note that only that distribution labeled 2 has no peak superimposed on the emission curve. Distribution 1 was used to calculate the data for the curve of Figure 7, and the temperature profile used in each of the calculations is shown in Figure 10. Note the high altitude warming trend that contributes to the sharp peaks at the center of the lines.

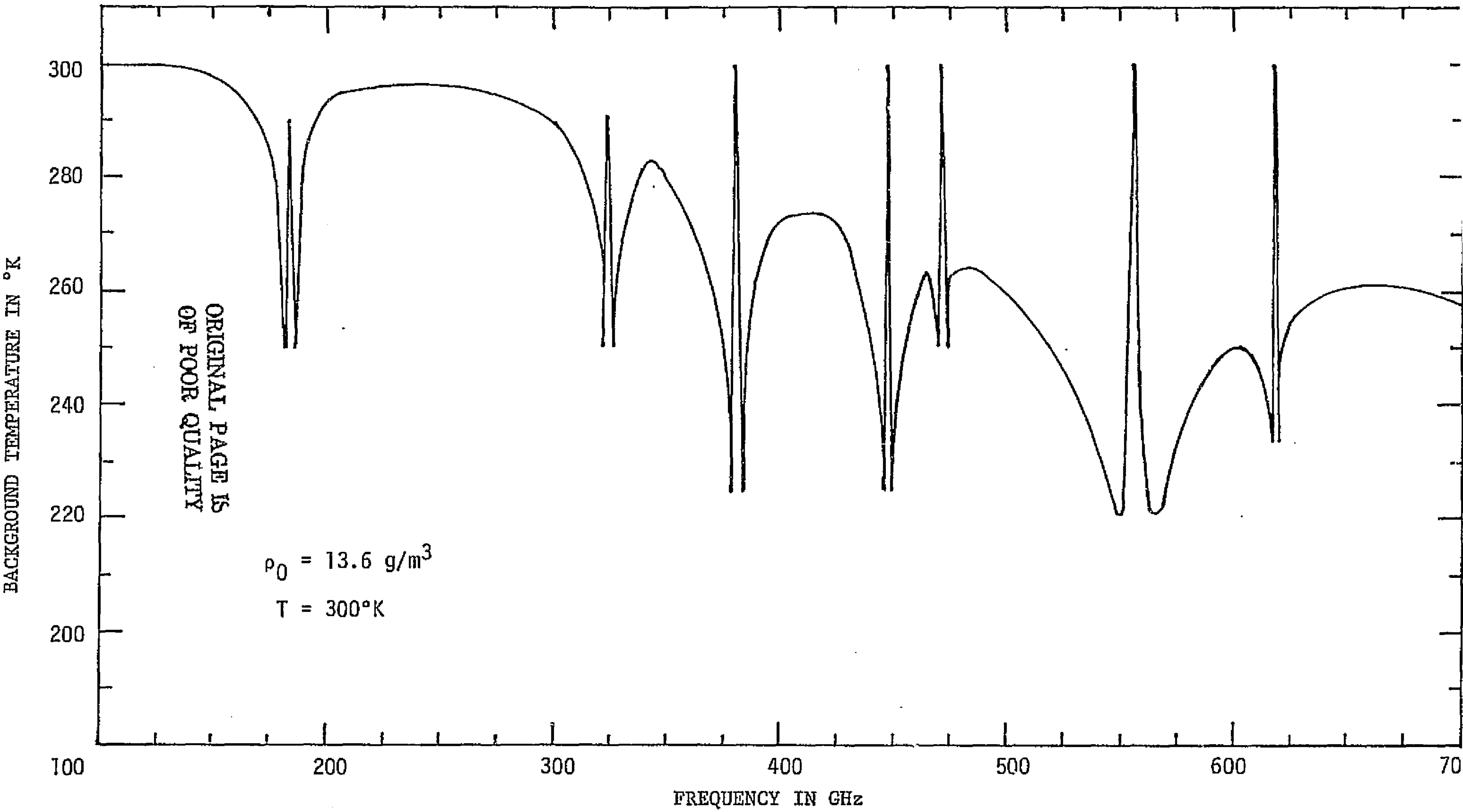

Figure 7. Background temperature due to H_2O measured from orbit.

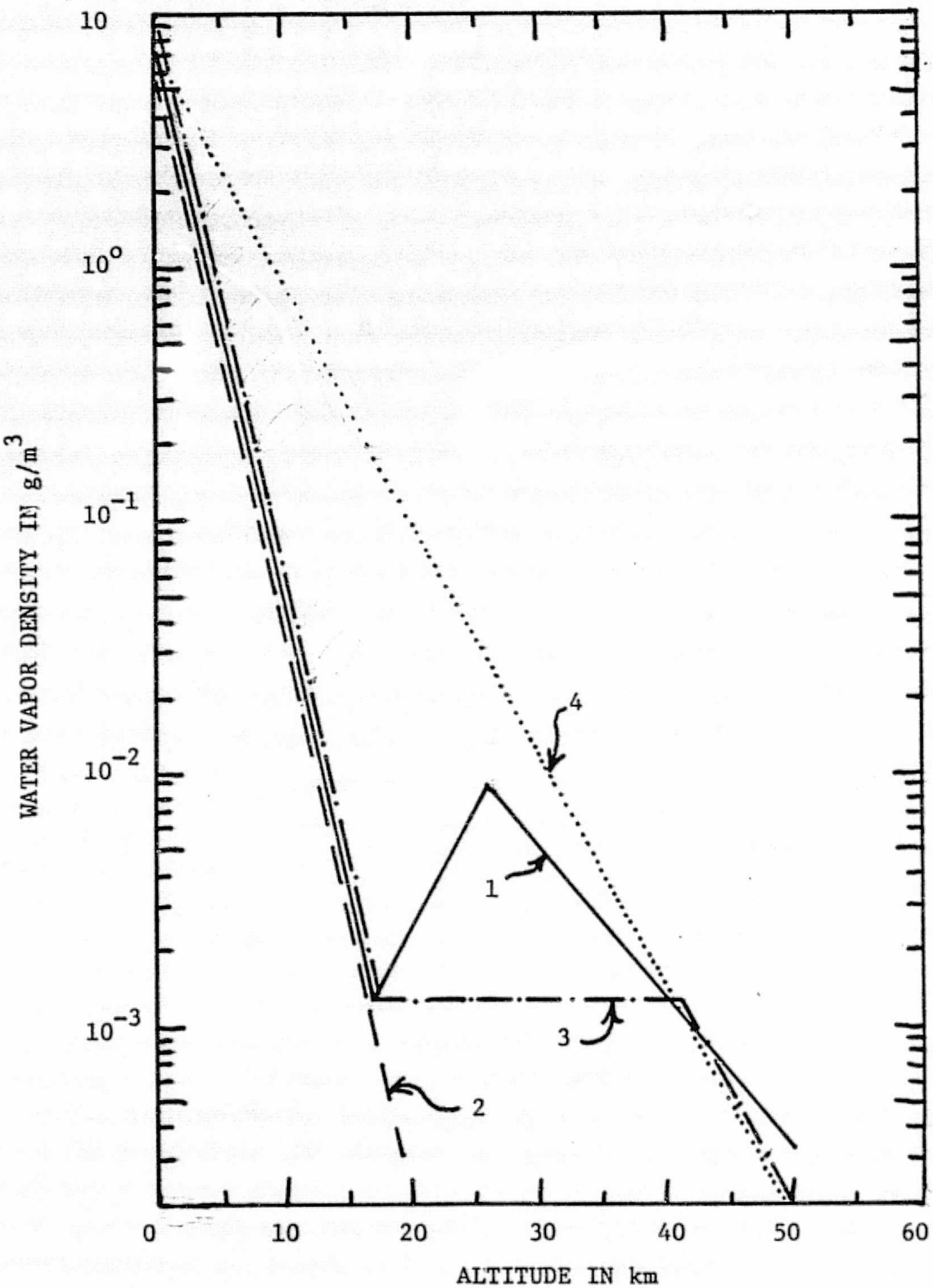

Figure 8. Water vapor density profiles for calculations of antenna temperature. Numbers on this graph correspond to those on Figure 9.

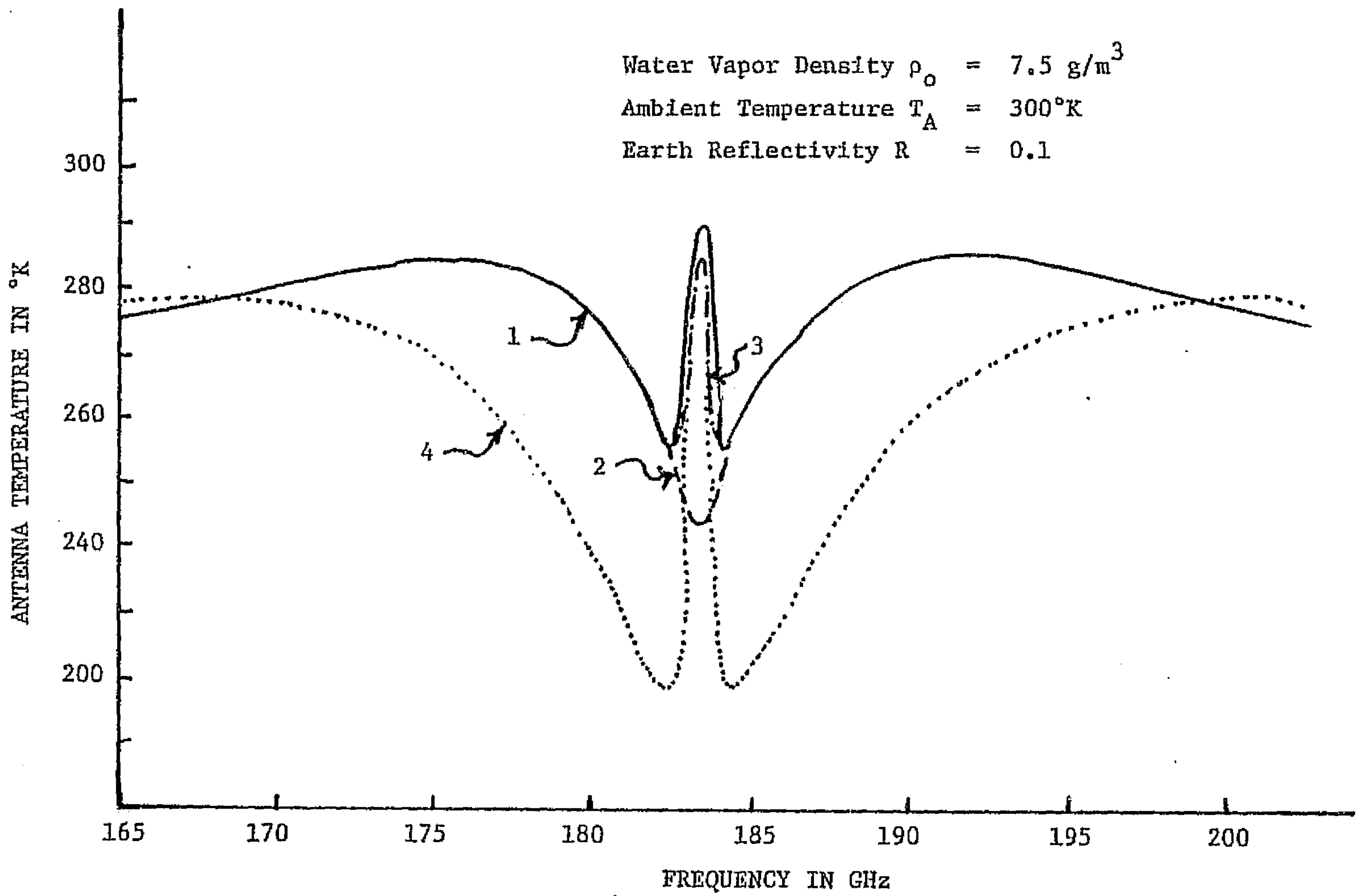

Figure 9. Antenna temperatures of 183.3 GHz water vapor line for various altitude distributions.

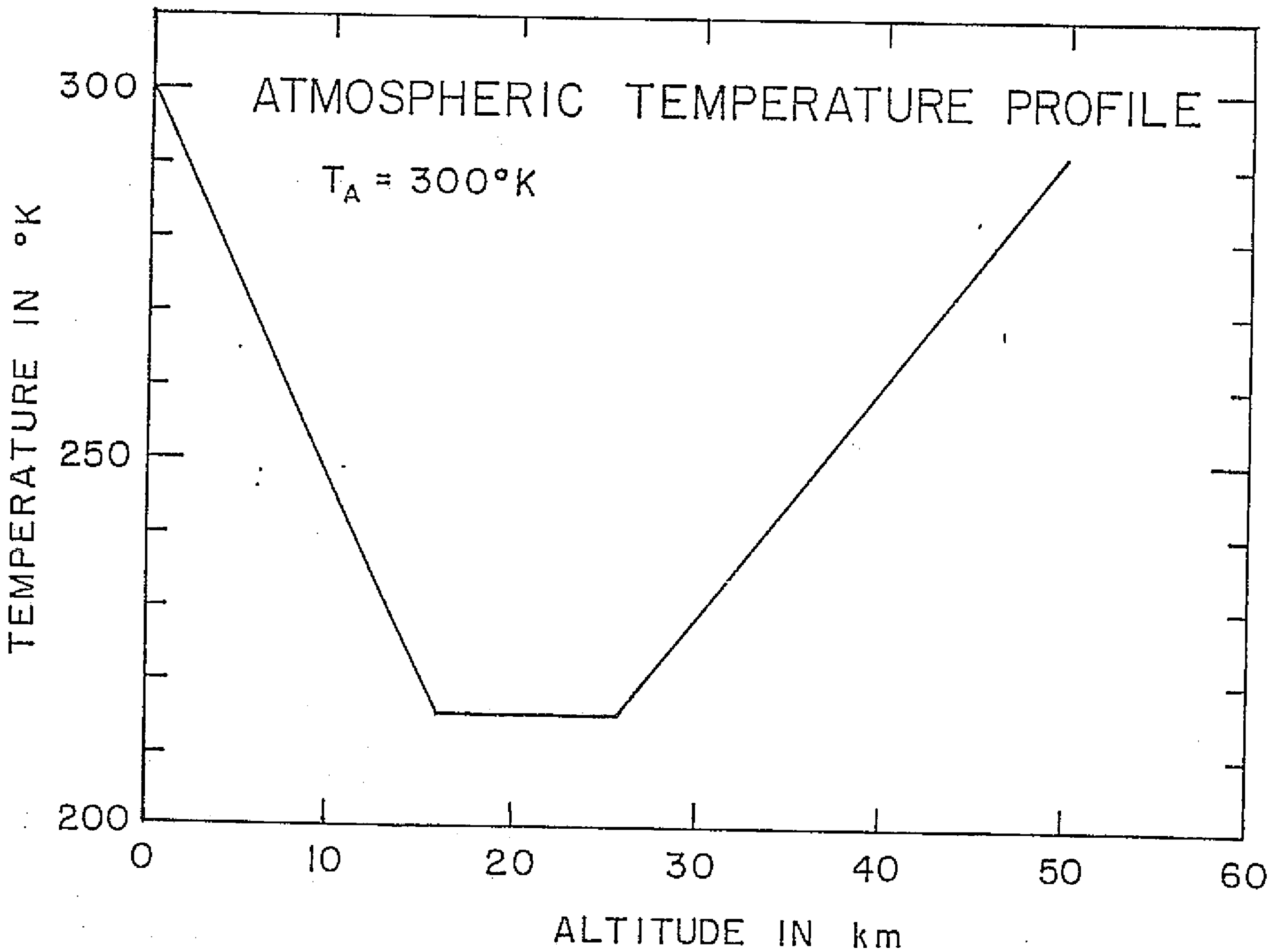

Figure 10. Temperature profile used in calculations of antenna temperature.

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These water vapor and temperature profiles are taken from papers by Croom [1, 2], who based his distributions on U. S. Air Force data; and by Barrett and Chung [3], who proposed a method of detecting high altitude water vapor by ground-based observations of the 22.235 GHz water absorption. It is not known whether a measured line shape could be used to determine a corresponding water vapor distribution, but the observation of a sharp peak in emission will almost certainly indicate the presence of high altitude water vapor.

4.0 QUASI-OPTICAL CALCULATIONS

The wire grid array shown in Figure 11 has been studied extensively during this program because of its potential application as a quasi-optical diplexer, and for other applications. Note that this array is a Fabry-Perot interferometer whose reflectors are each comprised of a pair of grids oriented at a relative angle $\gamma = \theta - \alpha$ and separated by phase shift ϕ_1. The phase shift between reflectors is ϕ_3. This configuration has the interesting property of being able to twist the polarization of incoming radiation and also has a bandpass that varies with either $\theta - \alpha$ or ϕ_1.

During this program, expressions for phase and polarization sensitive transmission and reflection of this interferometer have been derived. More recently, equations for power transmission, reflection, and loss have been obtained. This power transmission equation was given in the thirty-second monthly progress report (MPR) dated 15 February 1977. The equations for reflection and loss are simply too unwieldy to give in this report, and are also too cumbersome for use in drawing conclusions about grid filter performance. Further simplifications or approximations are necessary to reduce them to a tractable size.

These equations were derived from transmitted amplitude A_{TF}, and reflected amplitude A_{RF} by using the following relations:

$$T = A_{TF}^* A_{TF},$$

$$R = A_{RF}^* A_{RF},$$

$$\text{and } T + R + L = 1, \tag{2}$$

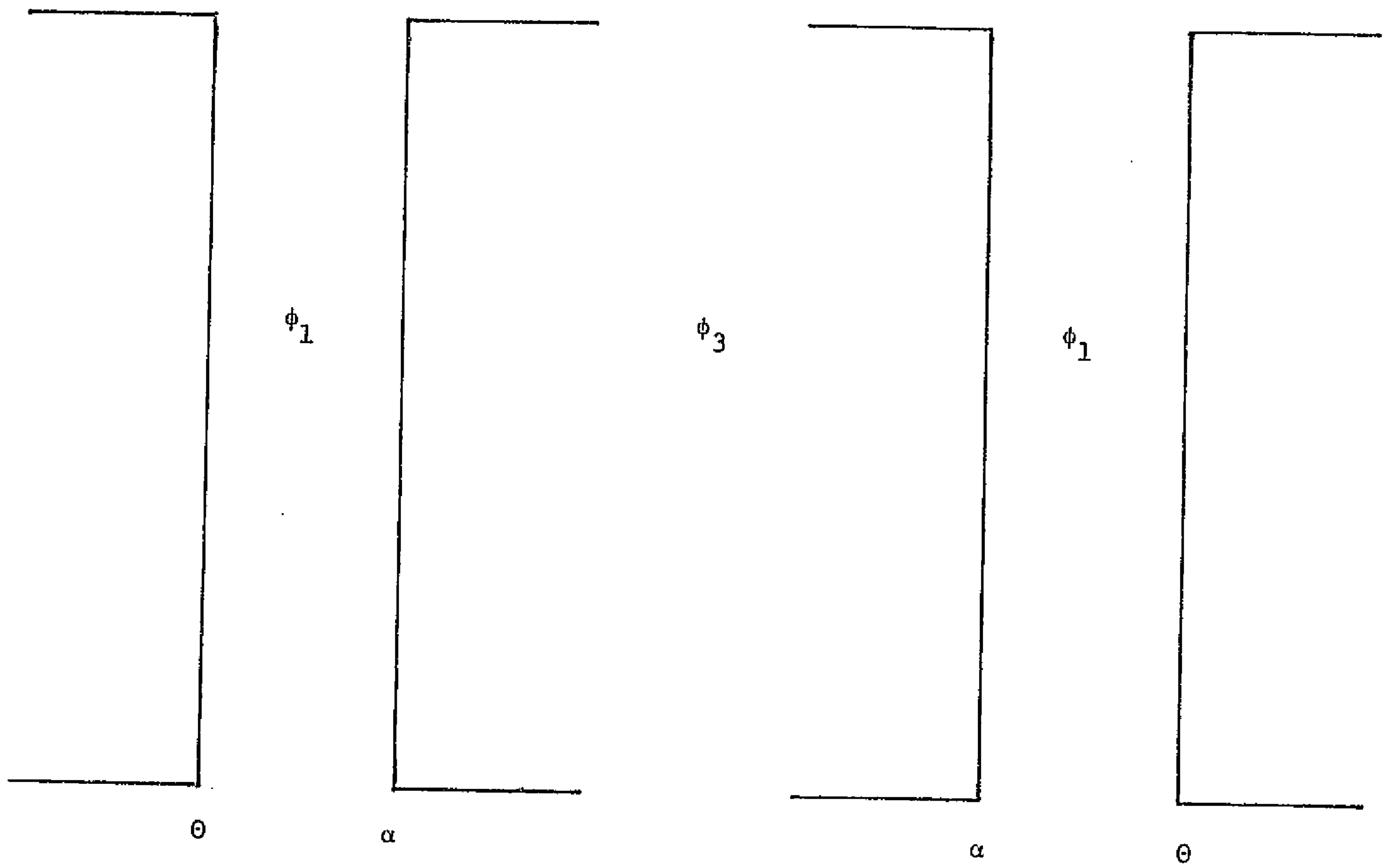

Figure 11. Two Pairs of Grids Forming an Interferometer.

where R, T, & L are transmission, reflection and loss respectively. As a check on the derivations, it has been verified that T + R = 1 when L = 0. In deriving these equations, an error was found in the transmission equation given in the thirty-second MPR. This was a typographical error because the equation was correctly derived, but the version in the report was used to make some calculations. The equation may be corrected by simply squaring the first term in the denominator of the transmission equation, which is Equation (3) in the thirty-second MPR. This change appears to be fairly insignificant, but it has a great effect on the influence of losses on the transmission of this type filter. Figures 12 and 13 are curves of interferometer transmission related to phase shift and frequency respectively for transmission and reflection losses of 0.1% (R = T = 0.999), calculated using the corrected equation. These curves show a loss in peak transmission of approximately 8 dB if the grid angles are increased from 60° to 89°, but the filter bandpass decreases significantly over this angular range. It is anticipated that the indicated correction will cause better agreement between calculated and measured values to be obtained.

5.0 EFFORTS PLANNED FOR THE FIRST HALF OF 1978

5.1 Calculations

Unless some interesting special case such as that treated in Section 3.0 requires attention, radiometric and propagation calculations will not be made. However, radiometric calculations will be made to support the 183 GHz measurement effort as required.

The derivation of reflected and lost power for the four-grid arrays almost finishes the analytical work in this area. Note that the cases treated thus far are specialized and that the general case of arbitrary grid angles and phase shifts has not yet been attacked. Because of the great complexity of this general calculation, only the case of polarization twisting on transmission will be considered. Most of the quasi-optical calculations made during the next reporting period will be made in support of component development.

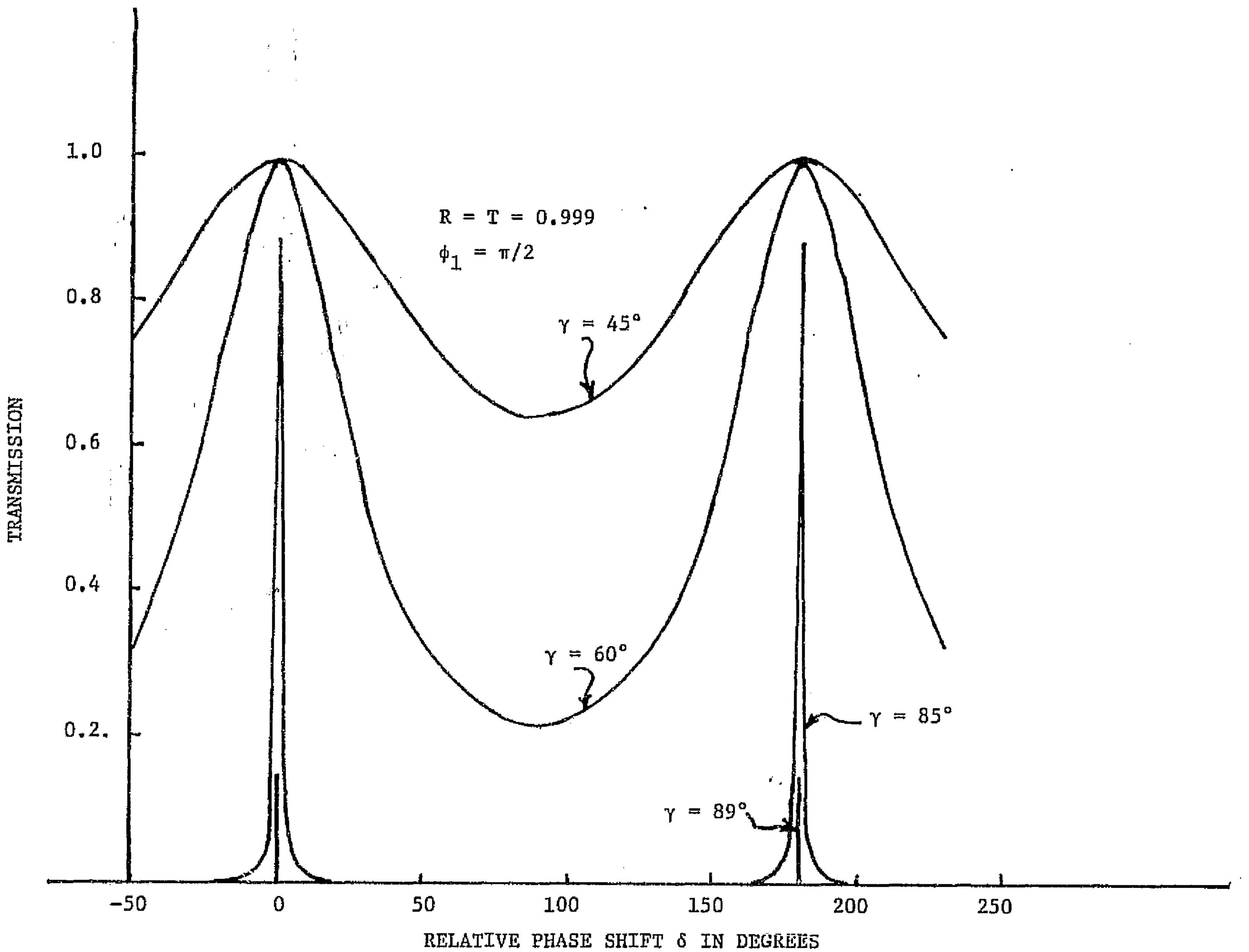

Figure 12. Grid interferometer transmission as a function of phase shift.

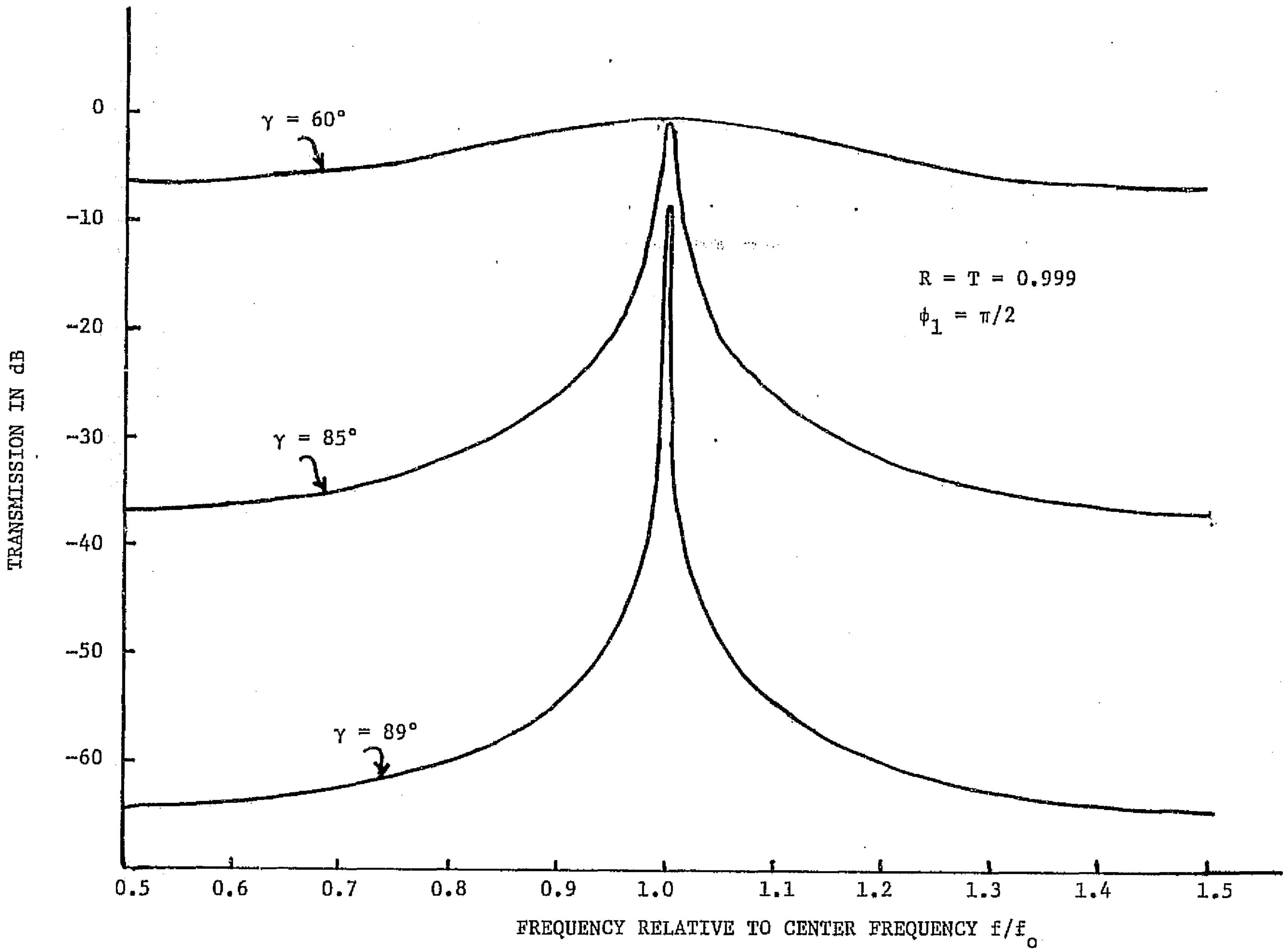

Figure 13. Grid interferometer transmission as a function of frequency.

5.2 Measurements

Since the split block mixer has been received, measurements of its performance using Wrixon and Mattauch diodes can be made. The noise figure test facility, described in earlier reports, will be put into operation to effect these measurements.

Radiometric measurements on the 183 GHz water vapor transition will continue, and the measurement spectrum will be expanded to include the range 160-200 GHz with the addition of another klystron.

With the solution of the spring mounting problem, the 183 GHz subharmonic mixer will be ready for test early in 1978, provided that the diodes can be successfully contacted.

5.3 Component Development

Subharmonic mixer development will continue, and it is anticipated that this work will result in a useful mixer during the next six-month period. If tests of this mixer are successful, an attempt will be made to extend the technology to the $f_s/4$ pumping case, since modeling results on this case have been encouraging.

Using analytical results already obtained and grids made in-house and by Jerry Lamb of GSFC, methods of building millimeter wave quasi-optical components will be studied. Components of interest include isolators, diplexers, duplexers, and circulators.

REFERENCES

1. D. L. Croom, "Stratospheric Thermal Emission and Absorption Near the 22.235 Gc/s (1.35cm) Rotational Line of Water-Vapour", J. Atmos. & Terr. Phys. 27, 217 (1965).

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3. A. H. Barrett and V. K. Chung, "A Method for the Determination of High-Altitude Water-Vapor Abundance from Ground-Based Microwave Observations", J. Geophys. Res., 67, 11, 4259 (1962).

APPENDIX

Monthly Reports Thirty-Seven through Forty-One

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Thirty-Seventh Monthly Progress Report

Report Period
15 July to 15 August 1977

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Project Director: R. W. McMillan
Project Monitor: J. L. King

Engineering Experiment Station
Electromagnetics Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

SUMMARY OF WORK

1.0 Mixers

Machining of the 183 GHz subharmonic mixer body is essentially complete with the only remaining fabrication involving the mounting of flanges, tunable shorts and micrometer adjustments. The mixer is expected to be completed during the next reporting period.

Dr. Bob Mattauch of the University of Virginia, as a consequence of conversations with Vernon Brady, is sending four diode chips to Georgia Tech. The diodes are expected to arrive during the week of August 15. A careful study is being conducted to determine the optimal test procedures such that diode performance is maximized and the program efficacy and results are enhanced. Dr. Mattauch has also expressed a desire to visit Georgia Tech during September.

2.0 Radiometric Measurements

Subsequent to making the radiometric measurements described in the Semi-Annual Progress Report of 15 July 1977 additional problems were experienced with the 183 GHz radiometer. Due to some manifestation of mechanical stress in the mixer mount, the diode has had to be recontacted several times. Analysis of the problem revealed a suspect whisker spring and since installation of a new whisker, the diode junction has remained physically intact; however, the diode noise figure has deteriorated since initial contacting. If the diode chip continues to show evidence of excessive noise it will be replaced. The recurrence of interference due to external radiation has also been observed and localized to some source(s) imaged by the south window of the roof lab. Addit[illegible]nal electromagnetic shielding may be required to prevent erratic radiometer outputs.

3.0 Quasi-Optical Measurements

An improved version of the spindle wrapping method discussed in the Semi-Annual Progress Report of 22 July 1976 has made it possible to fabricate

free-standing (no substrate) wire grids from 0.125 mm (5 mil) copper wire by a method that eliminates pulling the wires away from the adhesive. The wires also have 0.125 mm spacing which should make the grids useful up to 300 GHz based upon the criterion of $\frac{1}{8}$ wavelength spacing for near ideal performance on reflection. Transmission and reflection measurements of these devices at 50 GHz are being made, and a four-grid filter will be constructed upon completion of the measurements. Figure 1 is a photograph of two of these grids.

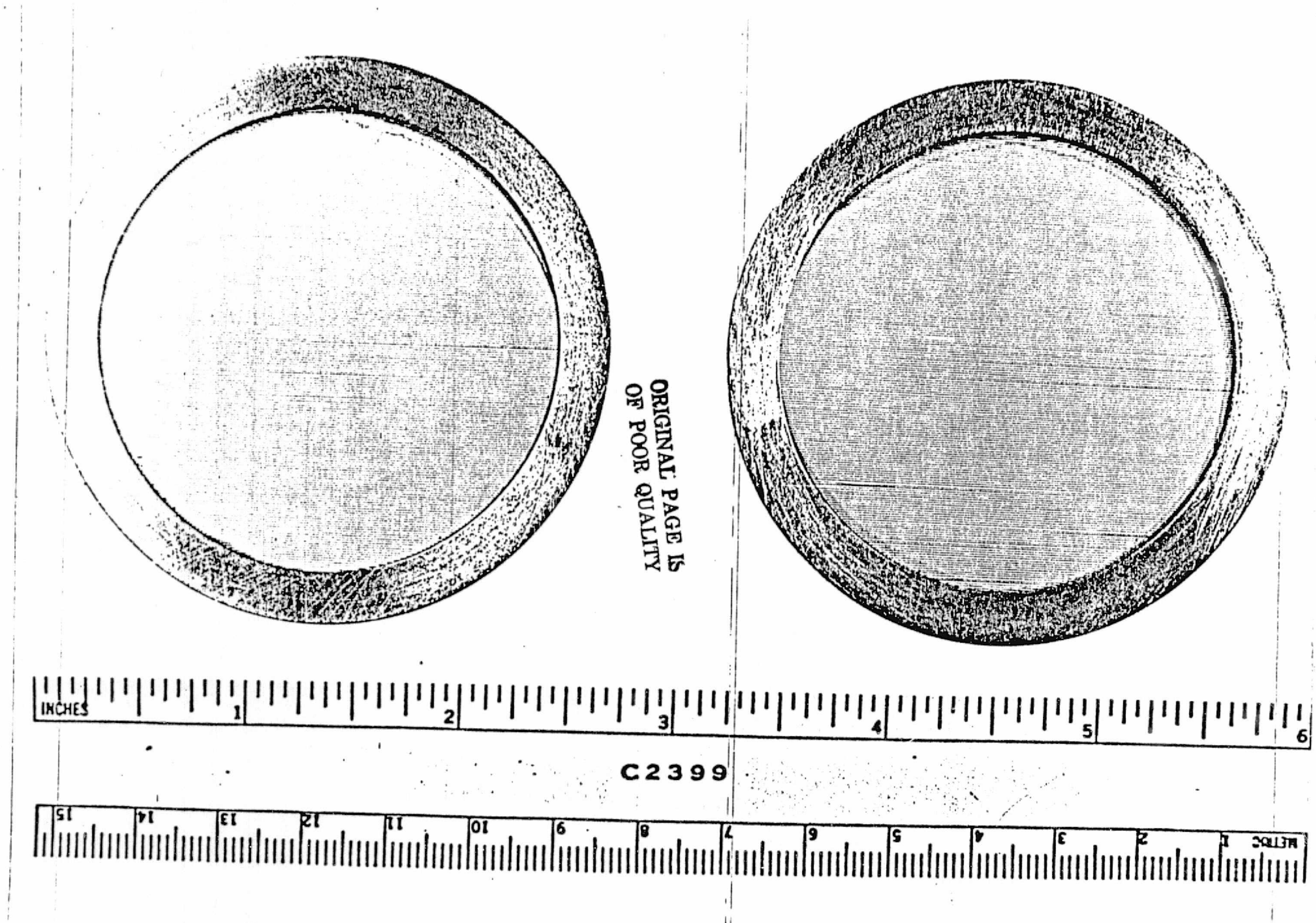
4.0 Radiometric Calculations

Radiosonde data measured at Thule Air Base, Greenland, during the period 31 March to 5 April 1977 has been received. The data format is radiosonde chart recorder output, annotated by pressure, temperature, and dew point readings at various altitudes. Dew point data were generally not available at altitudes above 6 KM, necessitating an extrapolation or assumption of the water vapor density profile above this altitude. This poses only a minor problem for the interpretation of the "down-looking" data obtained from the Convair 990 flights, because the majority of data were generated at 6 KM.

Figures 2 and 3 show temperature and water vapor density profiles obtained from the radiosonde data. The curves show three different measurements made on 2 and 4 April, which are simultaneous with the Convair 990 flights. Temperature can be extracted directly from the Weather Bureau charts, but water vapor density must be derived from psychrometric charts and gas laws as a function of dewpoint and pressure data. Because there was little spread in the data, "best-fit" straight lines were constructed on the graphs to generate an analytical expression for temperature and water vapor distribution for use in the computer program.

Based upon the reduced meteorological data, calculations of predicted "down-looking" antenna temperatures from 6 Km altitude were produced for both water and ice. Figure 4 illustrates once again that it is possible to image the ground in the 5 GHz radiometer channel. Figure 5, in contradistinction with the "down-looking" data, shows attenuation as a function of

Figure 1. Wire Grids



Wire Grids

frequency, looking up from the ground to 6 KM under the conditions described above. The calculations predict a radiometric temperature difference of approximately 10°K between water and ice, in good agreement with preliminary Convair 990 radiometric data. The temperature difference predicted for the 1 GHz channel is less than 0.1 degree, and would not be detectable with the Georgia Tech radiometer.

5.0 Plans for Next Period

The completion of the 183 GHz version of the subharmonic mixer is anticipated during the next reporting period, and preliminary tests will commence. Diodes from Dr. Mattauch will be received and the optimal test procedure will be selected. Additional radiometric measurements of the 183 GHz absorption line will be attempted and construction and initial testing of a new four-grid filter, using the new copper grids, will be undertaken.

J. Hank Rainwater for R. W. McMillan

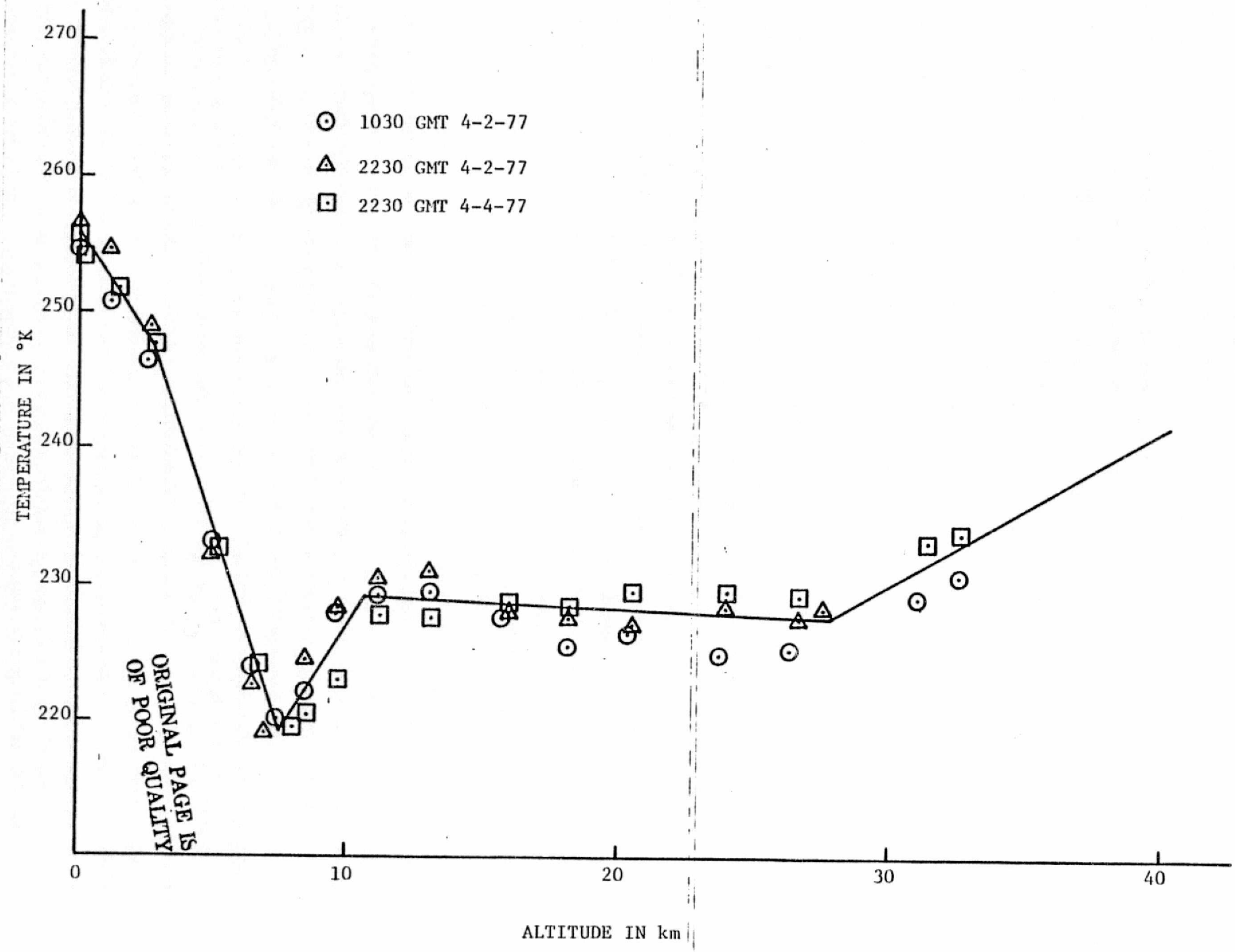


Figure 2. Temperature Distribution, Thule Air Base, Greenland

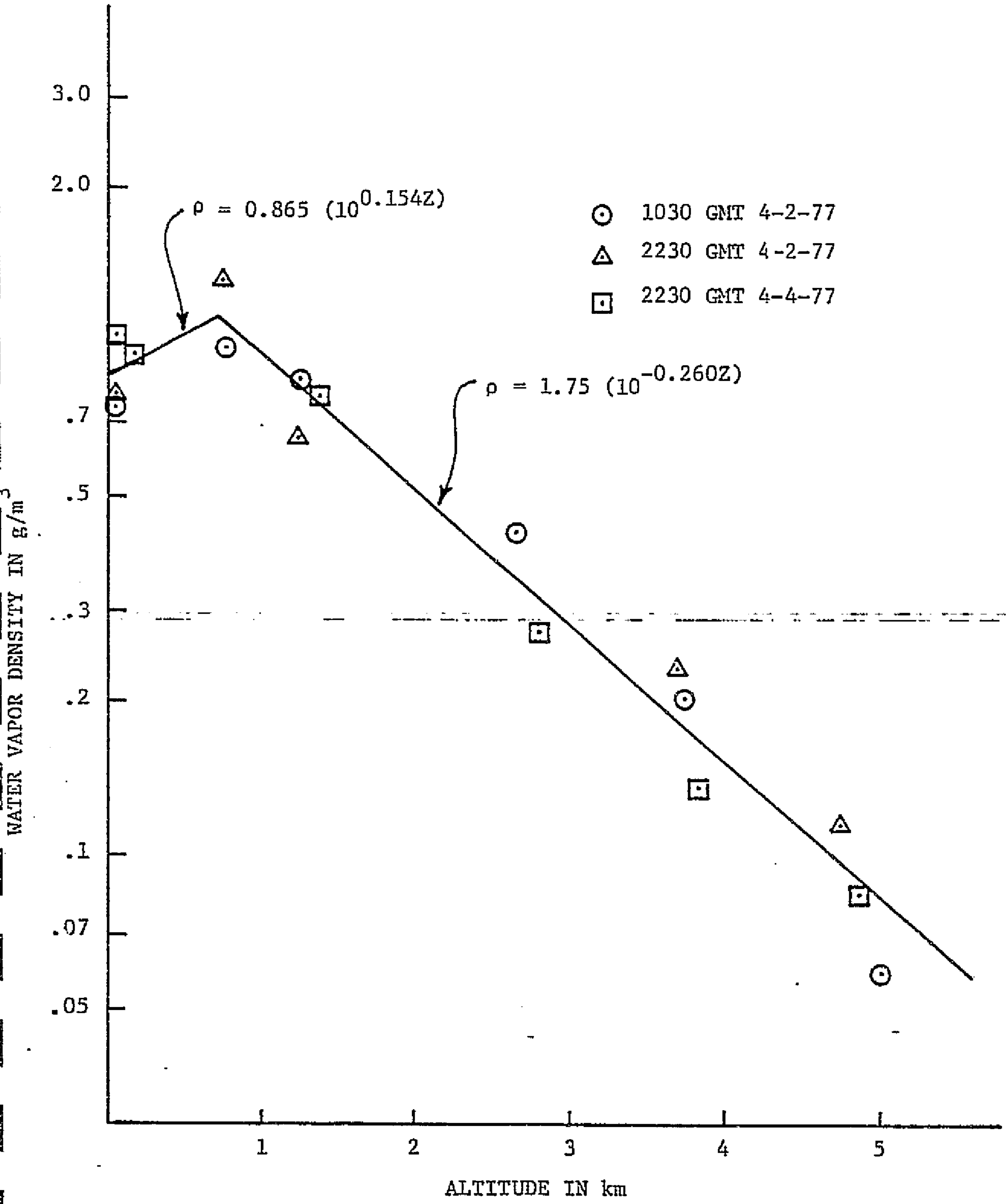


Figure 3. Water Vapor Distribution, Thule Air Base, Greenland

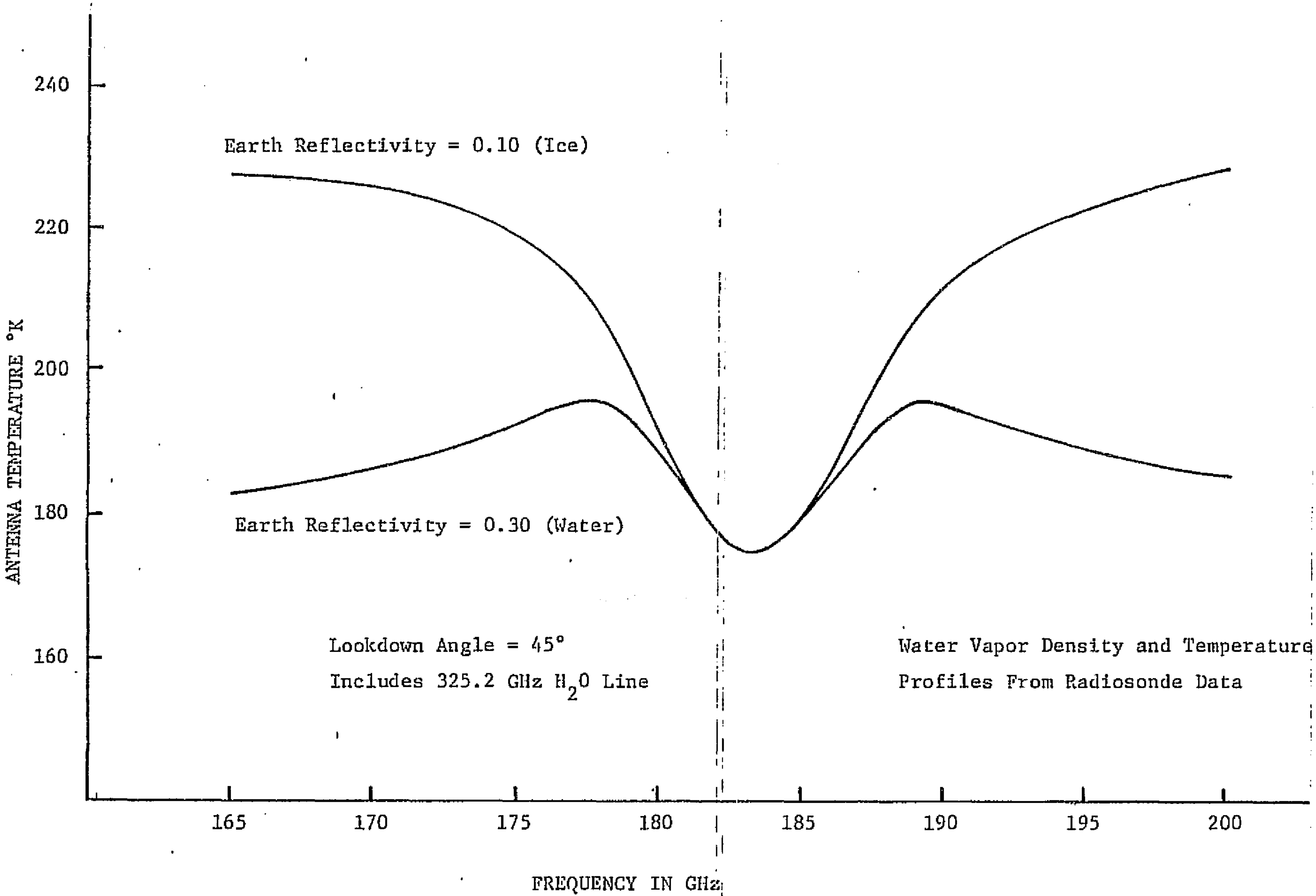


Figure 4. Antenna Temperature Looking Down From 6.1 km (20,000 ft.)

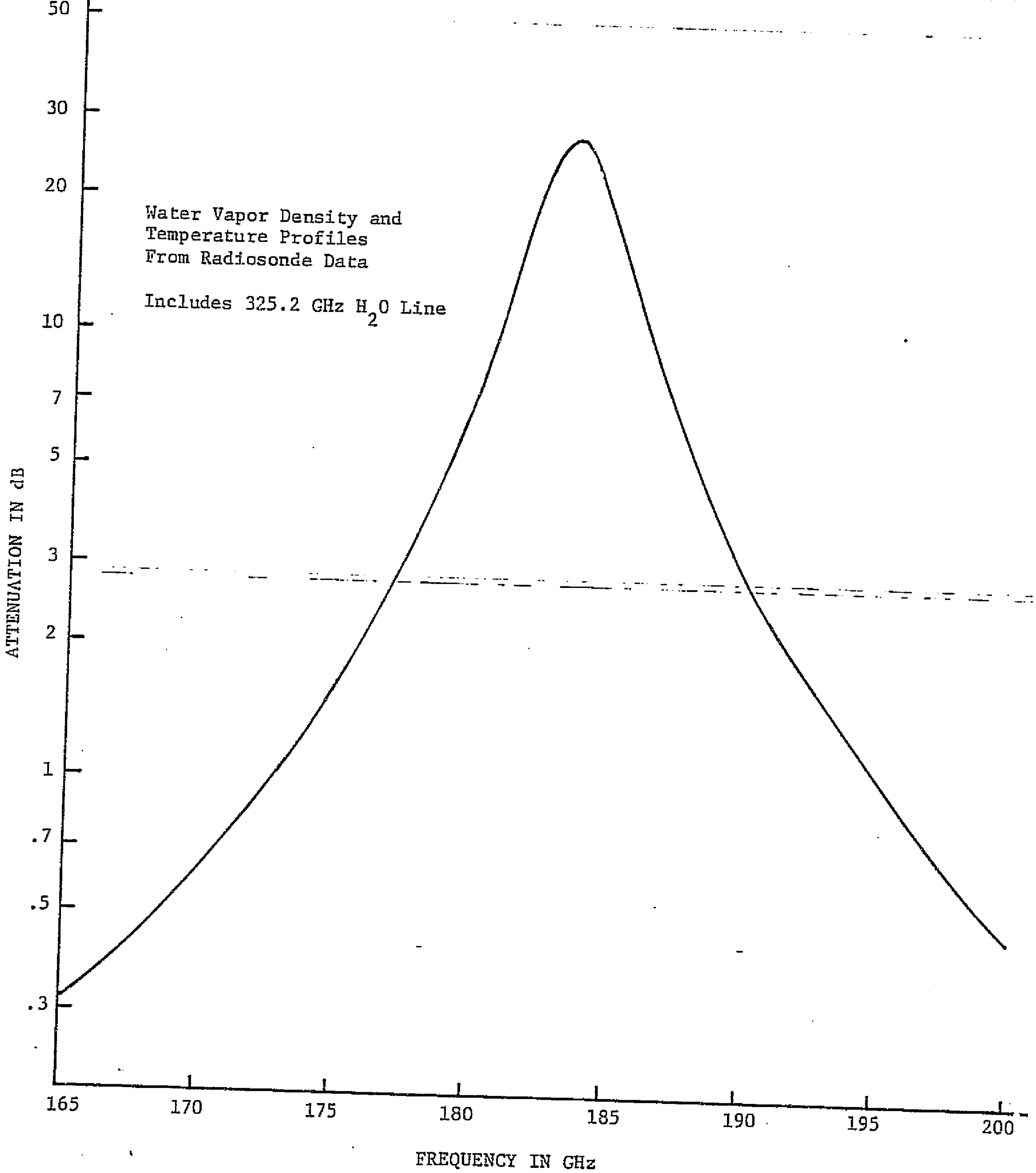


Figure 5. Total Attenuation to 6.1 km at 45° Angle

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Thirty-Eighth Monthly Progress Report

Report Period
15 August to 15 September 1977

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Project Director: R. W. McMillan
Project Monitor: J. L. King

Engineering Experiment Station
Electromagnetics Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

SUMMARY OF WORK

1.0 Mixers

Machining and assembly of the 183 GHz subharmonic mixer is complete except for mounting the stripline circuits when they are received. The mixer body must yet be gold plated, but it has been decided to wait until after a final trial assembly to perform this operation. Figures 1 and 2 are photographs of the assembled mixer showing all flanges and tunable shorts.

Because of the ease of mounting and removing diode chips, it has been determined that the B-57 mixer is the best vehicle for use in testing and comparing Schottky barrier diodes furnished by Drs. Mattauch and Wrixon. Some difficulty has been experienced in comparing diodes in the Sharpless wafer mounts because of differences in the wafers and because of greater difficulty in mounting and removing the chips. This mixer was discussed in the semi-annual status report of 15 July 1977. Unfortunately, delivery problems are being experienced with this mixer, and an alternative testing approach may be necessary if these problems persist.

The scale model subharmonic mixer is being modified slightly to allow for $\omega_s/4$ pumping. Additional quartz has been ordered to be used in fabrication of the new stripline circuits.

2.0 Radiometric Measurements

Two additional runs of radiometric data were made during this reporting period, and are shown in Figures 3 and 4. The Gross and Schulze-Tolbert calculated results obtained for $T_A = 311°K$ and $\rho = 20\ g/m^3$ are shown for comparison. For the 25 August run, the 3 points obtained with the higher frequency klystron, together with one of the points obtained with the lower frequency tube, are seen to fall precisely on the measured ambient temperature. After the measurements of 25-August, the higher frequency tube, which had evidenced increasingly erratic behavior, finally stopped oscillating altogether, so that higher frequency points were not obtained during the run

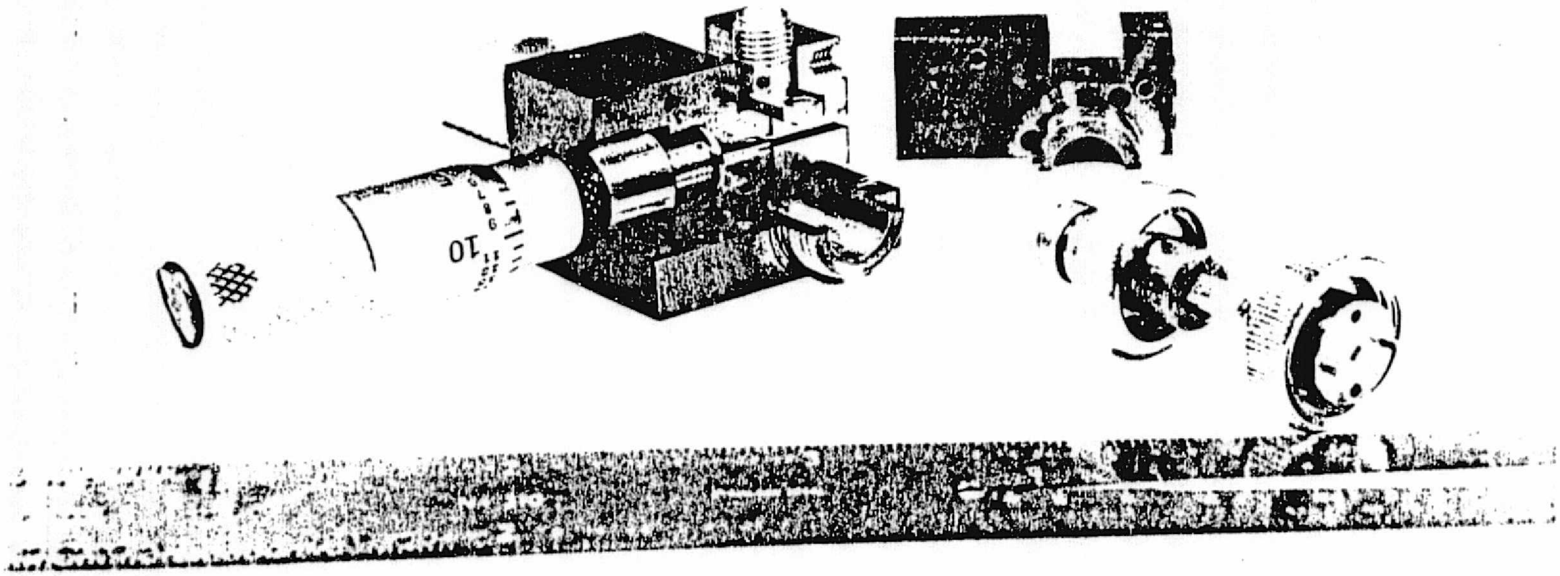


Figure 2. Photograph of partially disassembled 183 GHz subharmonic mixer showing interior construction.

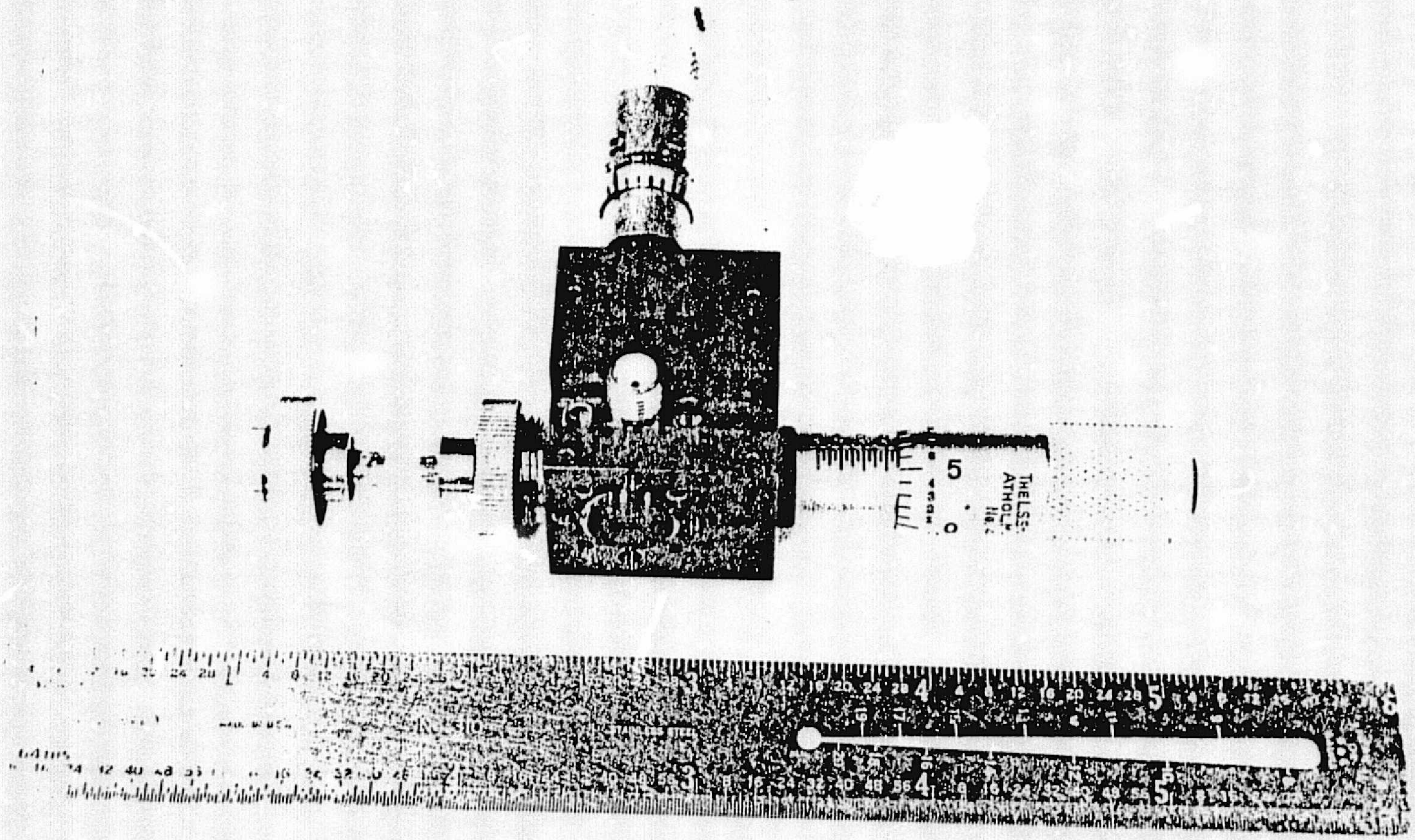


Figure 1. Photograph of assembled 183 GHz subharmonic mixer.

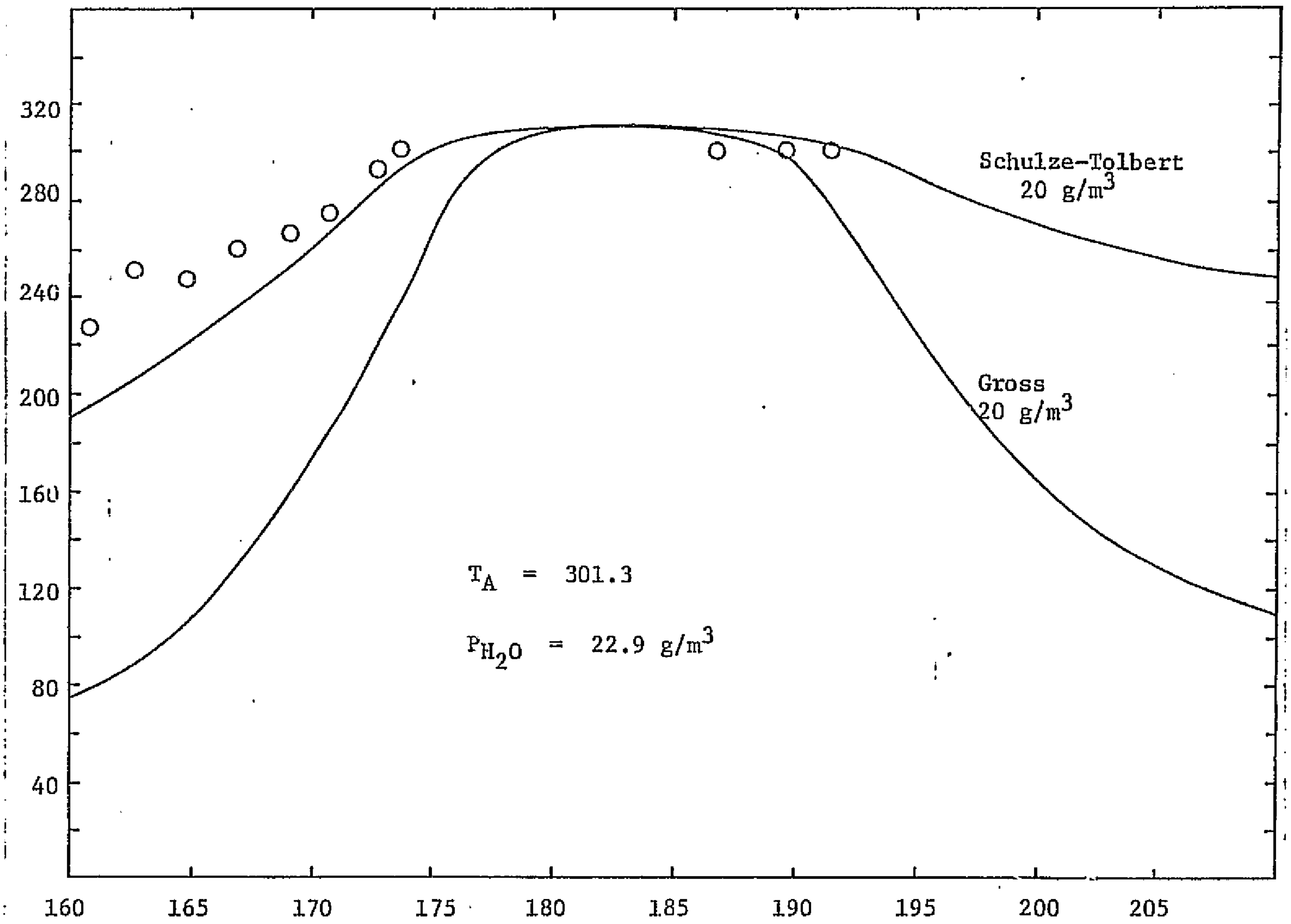


Figure 3. Zenith sky temperatures measured on 29 August 1977. The solid curves were calculated using Schulze-Tolbert and Gross line shapes, and the circles represent measured data.

of 29 August. The measurements of 29 August also show some structure, possibly caused by anomalous absorption, as discussed in the most recent semi-annual report. At the present time, the radiometer mixer is being recontacted, and these measurements will continue when the mixer becomes available.

3.0 Quasi-Optical Measurements

The interferometer bed used to make measurements of Fabry-Perot filter performance has been used almost continuously as a filter in the 183 GHz radiometer, and has not been available for additional quasi-optical measurements. For this reason, a new interferometer bed is being fabricated, so that these two sets of measurements can be made simultaneously. This new device is expected to be completed during the next reporting period.

4.0 Plans for Next Period

The B-57 mixer will hopefully be received from Custom Microwave, and testing of the Mattauch diodes will begin. Radiometric measurements will continue, and quasi-optical measurements will begin again when the new interferometer bed is complete.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Thirty-Ninth Monthly Progress Report

Report Period
15 September through 15 October 1977

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Principal Investigator: R. W. McMillan
Project Monitor: J. L. King

Engineering Experiment Station
Electromagnetics Laboratory
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Atlanta, Georgia 30332

SUMMARY OF WORK

1.0 Mixers

The stripline filters for the 183 GHz subharmonic mixer have been received from Jerry Lamb. These filters are apparently very well made in terms of having very precise circuit dimensions. When viewed under a microscope, the circuit lines are seen to be very sharp and straight, and it appears that these circuits will perform very well when mounted in the mixer body. During fabrication, an error of 0.005 inches was made in a mixer body dimension, which causes the stripline circuit to be placed slightly off center in the local oscillator waveguide input and also causes the IF output connecting wire to be 0.005 inches longer. These slight errors are not expected to significantly affect performance, but Jerry Lamb is fabricating modified circuits which will precisely fit within the mixer body, because it is important to eliminate all possible error sources in building a critically high-precision device such as this one. The available circuits are currently being mounted in the mixer body, and testing will proceed with the stripline circuits already received, because the errors involved are not considered large enough to affect performance to a significant degree.

The 6 GHz mixer model has been modified for $\omega_s/4$ pumping and some preliminary results have been obtained. It will be recalled that this mixer was originally designed to be modified in this way by changing a few parts associated with the LO waveguide input. Also, the quartz that was ordered for the new stripline circuit for this configuration mode has not yet been received, and the early measurements have been made with quartz left over from the $\omega_s/2$ pumping mode. Although these early results have been very encouraging, they are considered to be too preliminary to quote actual numbers.

The B-57 mixer which will be used for testing and comparing Schottky barrier diodes furnished by Drs. Mattauch and Wrixon has not yet been received, but delivery is expected about November 11, 1977. Since stripline circuits for the subharmonic mixer have been received, other mixer related

work including diode testing, will be subordinated in priority to the subharmonic work unless it contributes directly to the testing of this device.

2.0 Radiometric Measurements

Several additional measurements of radiometric antenna temperatures near 183.3 GHz have been made. An example of these measurements is shown in Figure 1, which is based on measurements made on 21 September. Measurements at the line peak agree well with ambient temperature, but the line skirts show some structure which is probably due to anomalous absorption as discussed in earlier reports. The calculated line shapes, shown as solid lines, are plotted for comparison only, and do not represent the conditions under which the measurements were made.

The radiometer mixer diode must be recontacted before additional measurements can be made. This repair will be done at a time when the subharmonic mixer work permits, because this latter effort has priority. It is expected that the ridged waveguide mixer, proposed for radiometer use in the proposal recently submitted for 1978, will be more reliable and give better results than the cross-guide mixer currently being used on the radiometer.

3.0 Quasi-Optical Measurements

The new interferometer bed which will be used to measure grid interferometer performance is complete, and will be used to make measurements on the wire grid interferometers during the next reporting period.

4.0 Plans for Next Period

The subharmonic mixer should have diodes mounted and contacted near the end of the next reporting period, and measurements will begin shortly afterward. Measurements of grid interferometer performance will also be made using the new interferometer bed. If subharmonic mixer priority permits, the radiometer mixer will be recontacted and more sky temperature measurements will be made.

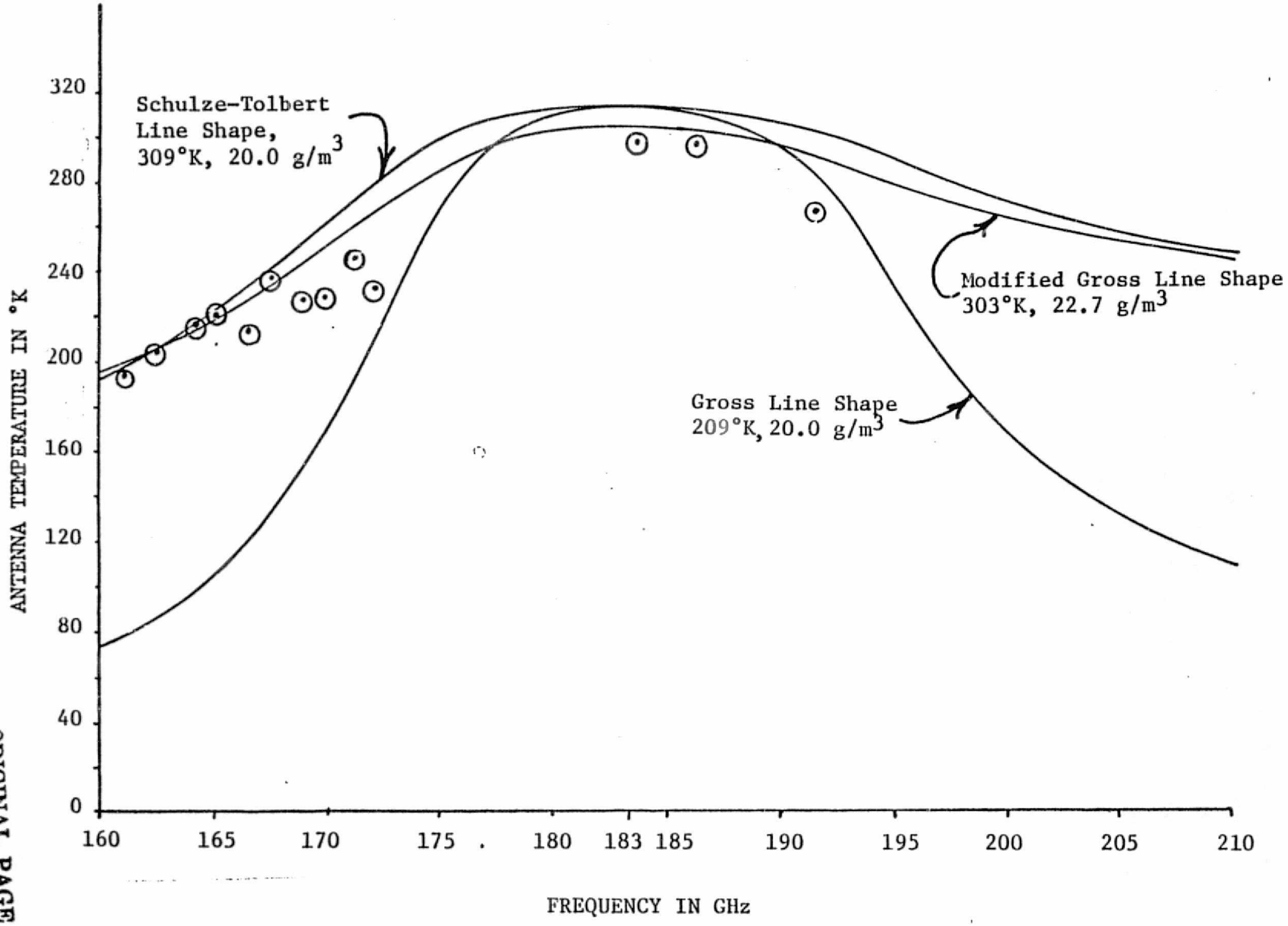

FIGURE 1. Antenna temperatures measured near 183.3 GHz on 21 September 1977. Circles represent measured data.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fortieth Monthly Progress Report

Report Period

15 October through 15 November 1977

NASA Grant No. NSG-5012

GT/EES Project No. A-1642

Principal Investigator: R. W. McMillan

Project Monitor: J. L. King

Engineering Experiment Station
Electromagnetics Laboratory
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SUMMARY OF WORK

1.0 MIXERS

Significant progress has been made in soldering the subharmonic mixer Schottky barrier diodes and whiskers to the stripline circuits, and in making springs from the whiskers when they are mounted. A number of dummy diodes have been successfully mounted, and a technique for mounting whiskers was developed during the past week. Because of the small size of these components, mounting techniques must be perfected by several trial runs using dummy diodes before actual soldering of the real diodes.

It is of interest to review the methods to be used in simultaneously contacting the two diodes of the subharmonic mixer. The method is shown schematically in Figure 1. Diodes and springs are first mounted on both the stripline circuit and the run-in post as discussed in the first paragraph, with one diode and one spring each mounted on the circuit and the post. The circuit is then secured in the mixer body. The diodes are then contacted by running in the post, as the diode curves are monitored through the IF output connector on an oscilloscope. Simultaneously, the operation is viewed through a microscope. It will be necessary to contact both diodes almost simultaneously, requiring that the springs be of near identical length. This operation is perhaps the most difficult step in the fabrication of a subharmonic mixer.

The quartz to be used in making the stripline circuit for the $\omega/4$ pumping model has been received. It is expected that some results will be obtained using this pumping method during the next reporting period. The B-57 mixer has still not been received from Custom Microwave, but delivery is expected early in the next reporting period.

2.0 RADIOMETRIC MEASUREMENTS

The radiometer mixer still has not been repaired because priority is being given to the subharmonic mixer work. It may be possible to repair this device after the subharmonic mixer has been contacted and during the time that it is being tested. It would be of great interest

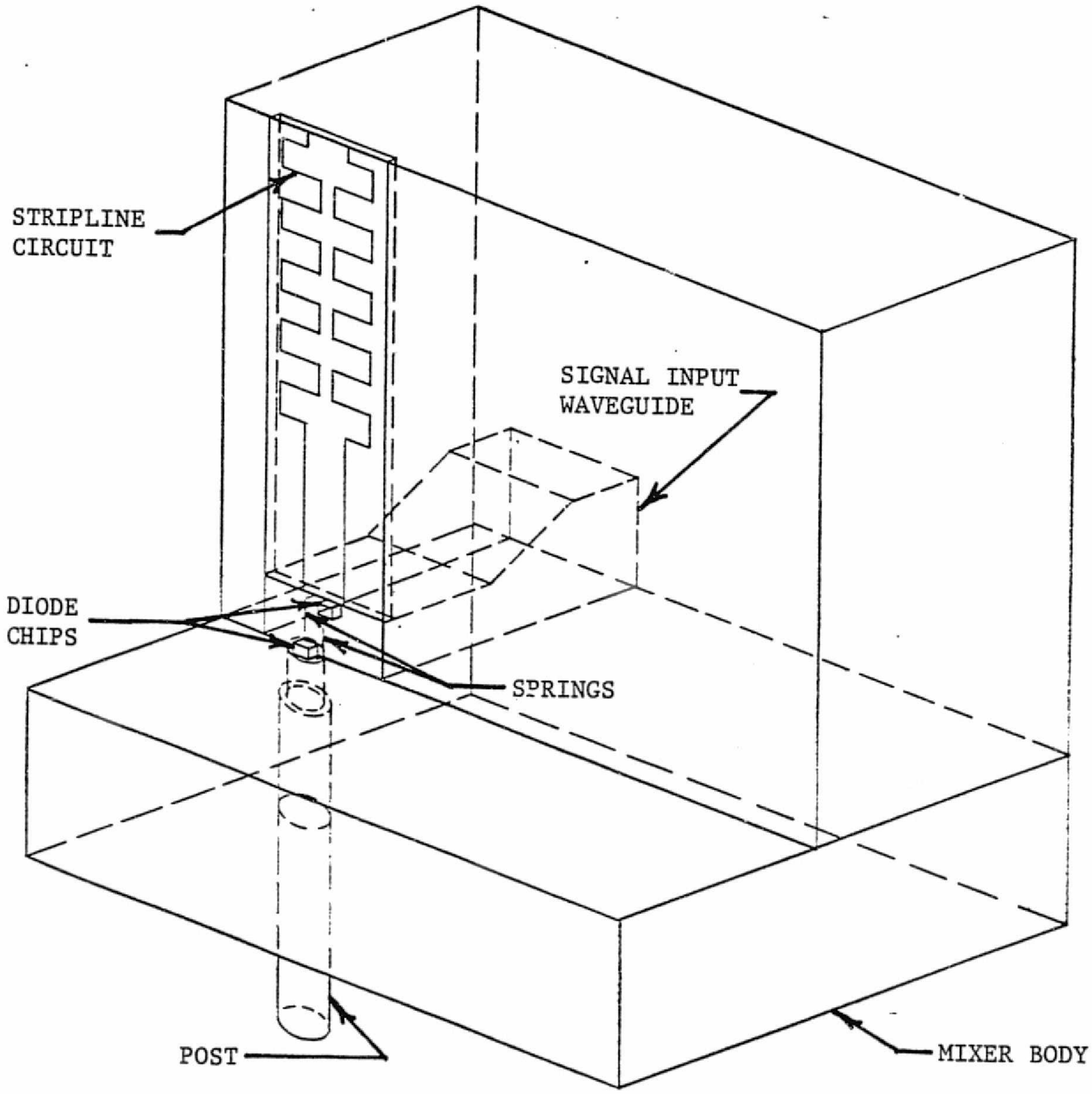

FIGURE 1. Cutaway view of a subharmonic mixer showing the relationship of components during the process of contacting diodes.

to obtain radiometric data on a clear, cool fall day because agreement with theory is expected to be better under these conditions. Better agreement results in this case because the low humidity usually prevalent on this type day is not conducive to the formation of clusters of water vapor molecules, which are thought by some spectroscopists to cause anomalous absorption in the millimeter wavelength region.

A total of three radiometer papers, supported wholly or partially by this grant, have been accepted for presentation at the Third International Conference on Submillimeter Waves and Their Applications to be held at Guildford, England in March 1978. The subjects of these papers are the 183 GHz radiometer, prediction of a peak at absorption center frequencies in down-looking radiometry, and measurement of zenith attenuation at 230 GHz. In addition, a slightly different version of the 183 GHz radiometer paper will be given at the ARPA Conference on Millimeter Waves to be held in late November. No word has yet been received on a fourth paper on the subject of wire grid interferometers, submitted to the Guildford meeting.

Dr. H. A. Gebbie of Appleton Laboratories in Slough, England visited our laboratory on 9 November to discuss the status of millimeter and submillimeter wave propagation measurements. He was very much interested in the results obtained with our 183 GHz radiometer because he feels that they confirm some of the anomalous absorption measurements that he has made in this wavelength region. He suggests that we keep each other informed of new results and that we consider some sort of cooperative effort in the future.

3.0 QUASI-OPTICAL MEASUREMENTS

The experimental arrangement used to measure transmission and reflection of wire grids at 50 GHz has been improved by replacing the small horns previously used by larger horns. Since some of the earlier measurements made with the smaller horns were suspect, a new series of experiments were carried out to determine transmission and reflection using these larger

horns. The larger horns give better results because the angular spread of the radiation is smaller, so that the beam is more nearly perpendicular to the plane of the grids over a larger portion of the grid area. As before, a total of 10 measurements of both transmission and reflection were made for each grid, and the means and standard deviations of these distributions were calculated. The results of these measurements are given in Table I. Note that the earlier grids made by Jerry Lamb give the best performance, contrary to what one would expect based on thickness of the conductors. Both the copper wire grids made in this laboratory and the new aluminum grids provided by Jerry are not performing as well as expected. Measurements of transmission and reflection of substrates, also provided by Jerry, are included in the table. It appears that a closer examination of wire grid theory must be made to account for the disparity in performance discussed above.

4.0 PLANS FOR NEXT PERIOD

Some preliminary 183 GHz subharmonic mixer results should be available during the next reporting period, as well as some results on the modeling of the $\omega/4$ pumping. If the subharmonic mixer work permits, the radiometer mixer will be recontacted and additional radiometric measurements will be made. Measurements of grid interferometer performance will be continued.

TABLE I. REFLECTION AND TRANSMISSION OF WIRE GRIDS AND SUBSTRATES

GRID/ SUBSTRATE NUMBER		TRANSMISSION: POLARIZATION PARALLEL TO WIRES	TRANSMISSION: POLARIZATION PERPENDICULAR TO WIRES		REFLECTION: POLARIZATION PARALLEL TO WIRES		REFLECTION: POLARIZATION PERPENDICULAR TO WIRES
		MEAN	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN
QO-4	(GSFC)	0	0.90	0.01	0.94	0.03	<0.01
QO-5	(GSFC)	0	0.90	0.01	0.94	0.03	<0.01
QO-6	(GSFC)	0	0.89	0.01	0.94	0.02	<0.01
QO-7	(GSFC)	0	0.89	0.01	0.94	0.02	<0.01
QO-8	(GSFC)	0	0.89	0.01	0.95	0.01	<0.01
QO-9	(GSFC)	0	0.89	0.01	0.95	0.02	<0.01
QO-100-1	(GSFC)	0	0.83	0.02	0.90	0.02	<0.01
QO-100-2	(GSFC)	0	0.84	0.01	0.91	0.02	<0.01
1	(GT/EES)				0.46	0.02	0
2	(GT/EES)				0.50	0.02	0
3	(GT/EES)	0	0.81	0.02	0.46	0.01	0
4	(GT/EES)	0	0.83	0.03	0.48	0.01	0

GRID/ SUBSTRATE NUMBER		TRANSMISSION: MEAN	TRANSMISSION: STD. DEV.	REFLECTION: MEAN
K-30	(GSFC)*	0.88	0.01	0.01
K-50	(GSFC)*	0.87	0.02	0.01
K-100	(GSFC)*	0.86	0.02	0.00
M-25	(GSFC)*	0.87	0.04	0.01
M-50	(GSFC)*	0.86	0.01	0.01
M-100	(GSFC)*	0.87	0.01	0.01

*Substrate only. Reflection and Transmission are not polarization dependent in this case.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Forty-first Monthly Progress Report

Report Period

15 November through 15 December 1977

NASA Grant No. NSG-5012

GT/EES Project No. A-1642

Principal Investigator: R. W. McMillan

Project Monitor: J. L. King

Engineering Experiment Station
Electromagnetics Laboratory
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SUMMARY OF WORK

1.0 MIXERS

In assembling the subharmonic mixer, some difficulty has been encountered in making springs from the diode whisker wires after the wires are mounted to the stripline circuit. The diode chip is first mounted on the circuit, followed by the adjacent whisker wire, which is attached with low temperature solder. An attempt is then made to form a spring in this wire by making two right-angle bends. In each of about six attempts to date, the wire has broken away from the stripline during this operation. Several alternative approaches are being tried, including forming the spring before soldering to the stripline, and different methods of attaching the spring to the stripline. If the spring is formed before attachment, some sort of jig for holding proper spring alignment must be devised. It is expected that this problem will be solved during the next reporting period.

Using new quartz substrates received in early October, optimized stripline circuits for the $\omega_s/4$ pumping configuration of the 6 GHz subharmonic mixer model have been designed. In evaluating the performance of this device, a conversion loss of 6 dB with a pumping frequency of 1.5 GHz has been achieved. However, the IF bandwidth over which this performance can be maintained is about half that obtained for the $\omega_s/2$ pumping case. Nevertheless, this is an important result, because it has the potential of reducing the millimeter wave subharmonic mixer pump frequency to a range in which reliable solid state sources have useful, low-noise power output. More quantitative results of measurements on this device will be given in the next progress report.

2.0 QUASI-OPTICAL MEASUREMENTS

The new interferometer bed constructed for evaluation of four-grid Fabry-Perot interferometers is being tested using grids obtained from Jerry Lamb of GSFC. Good qualitative agreement of transmission vs. phase with theory has been obtained, but peak transmission measurements do not agree well with theory. This problem has been attributed to stray reflections within the interferometer and to unwanted resonance modes. Improved absorbers, similar to those used on the Convair 990 radiometer, are being fabricated to relieve this problem. Figure 1 is a tracing of a scan made

at 70 GHz by driving the interferometer micrometer spindle with a low-speed motor. The conditions are shown on the figure. There is a small ghost resonance midway between the main resonances which is about 18 dB below these main peaks.

3.0 QUASI-OPTICAL CALCULATIONS

During the last few months, considerable effort has been expended in calculating the reflected power from a four-grid Fabry-Perot interferometer. This work was largely done on a spare-time basis and was not charged to the grant. This calculation is difficult to make because of the great complexity of the algebraic expressions. The expression for lossless reflection R has been determined to be

$$R = \frac{\sin^4\gamma[\sin\delta + \cos^2\gamma\sin(2\phi_1-\delta)]^2}{4\cos^4\gamma\sin^4\phi_1 + \sin^4\gamma[\sin\delta + \cos^2\gamma\sin(2\phi_1-\delta)]^2} ,$$

where the parameters are defined on Figure 1. Note that lossless transmission T and reflection R are related by T + R = 1, so that it is a simple matter to calculate reflection from the transmission expression derived earlier. This approach was not taken for two reasons: (1) it is useful to verify that T + R = 1 as a check on earlier work, and (2) the algebraic techniques used in deriving the above expression are useful in deriving a general expression for lossy grids, a task which will begin immediately. Transmission, reflection and loss L are related by T + R + L = 1, so that knowledge of T and R will give insight into the loss mechanisms in these grid arrays.

4.0 PLANS FOR NEXT PERIOD

It is expected that the subharmonic mixer spring problem will be solved during the next reporting period. Repair of the radiometer mixer, which has been subordinated to the subharmonic mixer work, will be done, and radiometric measurements will resume. Quasi-Optical measurements and calculations will continue.

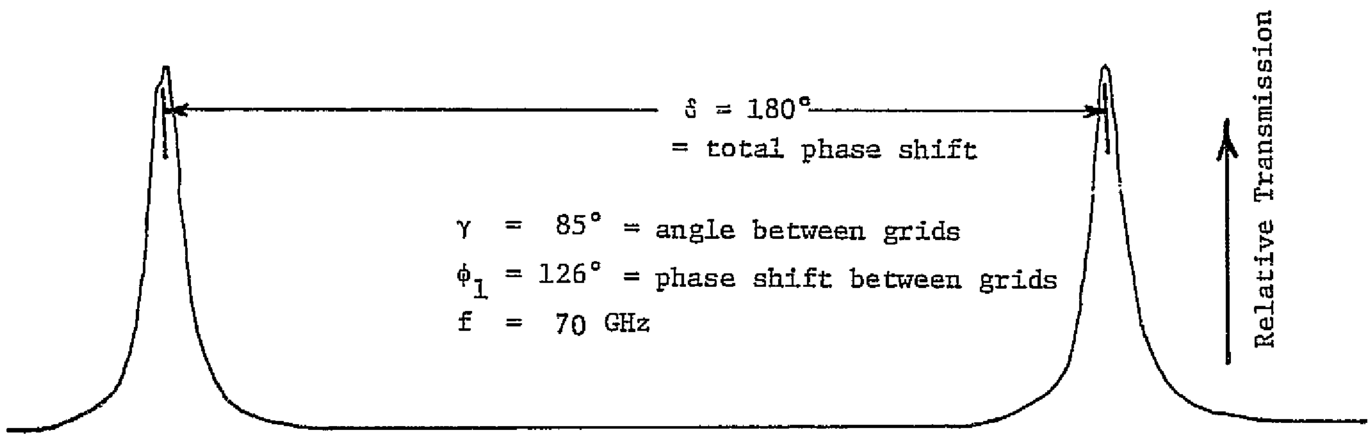

Figure 1. Adjacent resonances in a four-grid Fabry-Perot Interferometer.